Open University Geological Society Journal

Volume 35 (1–2) 2014
Combining the Dublin Symposium 2013 and OUGS Members' articles

Editor: Dr David M. Jones
41 Blackburn Way,
Godalming, Surrey GU7 1JY
e-mail: journal@ougs.org

The Open University Geological Society (OUGS) and its Journal Editor accept no responsibility for breach of copyright. Copyright for the work remains with the authors, but copyright for the published articles is that of the OUGS.

ISSN 0143-9472
© Copyright reserved

OUGS Journal 35 (1–2) 2014; published 2015; printed by Hobbs the Printers Ltd, Totton, Hampshire

Committee of the Open University Geological Society 2014–15

Society Website: ougs.org

Executive Committee

President: Dr Tom Argles, Department of Earth Sciences, The Open University, Milton Keynes MK7 6AA; president@ougs.org
Chairman: Linda Fowler; chairman@ougs.org
Secretary: Don Cameron; secretary@ougs.org
Treasurer: John Gooch; treasurer@ougs.org
Membership Secretary: Phyllis Turkington; membership@ougs.org
Newsletter Editor: Lyn Relph; news@ougs.org
Information Officer: Pauline Kirtley; info@ougs.org

Branch Organisers

Branch Organisers Representative: Jane Schollick: borep@ougs.org
East Anglia (EAn): Richard Kirkham; east.anglia@ougs.org
East Midlands (EMi): Sue Atkinson: east.midlands@ougs.org
East Scotland (ESc): Stuart Swales; east.scotland@ougs.org
Ireland (Ire): Susan Pyne; ireland@ougs.org
London (Lon): John Lonergan:; london@ougs.org
Mainland Europe (Eur): Elisabeth d'Eyrames: mainland.europe@ougs.org
Northumbria (Nor): Paul Williams: northumbria@ougs.org
North West (NWe): Jane Schollick: north.west@ougs.org
Oxford (Oxf): Sally Munnings; oxford@ougs.org
Severnside (Ssi): Janet Hiscott; severnside@ougs.org
South East (SEa): Elizabeth Boucher; south.east@ougs.org
South West (SWe): Rich Blagden: south.west@ougs.org
Walton Hall (WHa): Mrs Burti Montagu-Leon; walton.hall@ougs.org
Wessex (Wsx): Sheila Alderman; wessex@ougs.org
West Midlands (WMi): Sandra Morgan; west.midlands@ougs.org
West Scotland (WSc): Cliff Probert; west.scotland@ougs.org
Yorkshire (Yor): Ricky Savage; yorkshire@ougs.org

Other officers

(non-OUGSC voting)
Sales Administrator: John Lonergan; sales@ougs.org
Minutes Secretary: Linda McArdell; minsec@ougs.org
Journal Editor: Dr David M. Jones, 41 Blackburn Way, Godalming, Surrey GU7 1JY; journal@ougs.org
Archivist/Reviews: Jane Michael; reviews@ougs.org
Webmaster: Stuart Swales; webmaster@ougs.org
Deputy Webmaster: Martin Bryan; webdeputy@ougs.org
Gift Aid Officer: Ann Goundry; giftaid@ougs.org

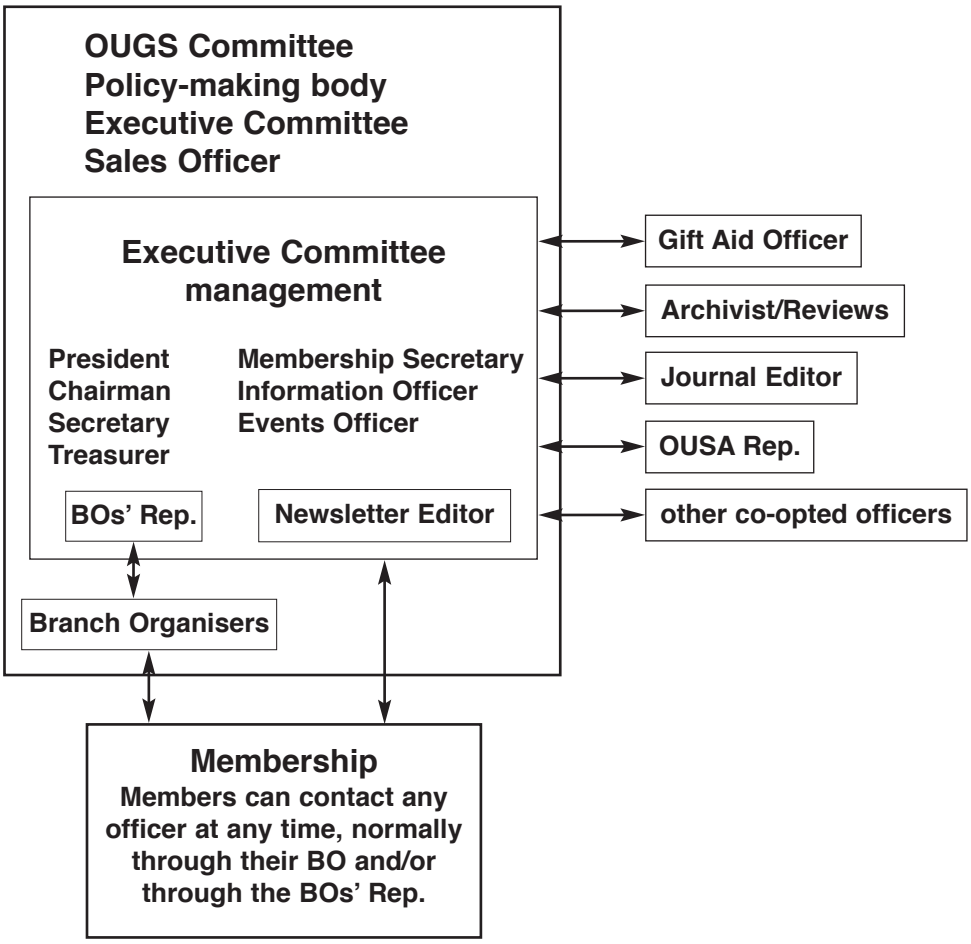
Vice Presidents

Dr Evelyn Brown, Dr Michael Gagan and Norma Rothwell: normarothwell@gmail.com

Past Presidents

1973–74 Prof. Ian Gass
1975–76 Dr Chris Wilson
1977–78 Mr John Wright
1979–80 Dr Richard Thorpe
1981–82 Dr Dennis Jackson
1983–84 Prof. Geoff Brown
1985–86 Dr Peter Skelton
1987–88 Mr Eric Skipsey
1989–90 Dr Sandy Smith
1991–92 Dr Dave Williams
1993–94 Dr Dave Rothery
1995–96 Dr Nigel Harris
1997–98 Dr Dee Edwards
1999–00 Dr Peter Sheldon
2001–02 Prof. Bob Spicer
2003–04 Prof. Chris Wilson
2005–06 Dr Angela Coe
2007–08 Dr Sandy Smith
2011–12 Dr Dave McGarvie
2012–13 Dr Nick Rogers

DISSEMINATION OF INFORMATION PATHWAYS



Editorial:

Dear readers,
This issue of the OUGS Journal *includes articles and abstracts as one issue for 2014, comprising articles and abstracts from the OUGS 2013 Symposium in Dublin, and articles and field trip reports from OUGS Members. Once again I am obliged to say that I sincerely apologise to members for another extremely late issue.*

First and foremost, I have an announcement. This is the last issue of our OUGS Journal *publication under this title. Beginning in 2015 we will publish our Annual Symposium articles, and articles and reports from OUGS Members under the title* Proceedings of the Open University Geological Society, *beginning with a new series numbering. In addition to articles and reports, the new* Proceedings *will also incorporate the* OUGS Annual Report, *the OUGS Constitution with any amendments required from AGM resolutions that have been passed, and the OUGSJ Index.*

The articles in this issue include, I am sorry to report, only one article from the OUGS Dublin Symposium 2013. Most of the speakers declared themselves too busy with other academic matters to have time to write up a brief article on his or her Symposium lecture for the OUGS. Transcriptions of our recordings of the lectures were provided to all speakers who asked us to prepare them. In one case, a speaker who asked for a transcription later declared that he did not have time to edit it or to write a brief article; he withdrew consent for us to use an edited version of his transcription that I had prepared for him. I apologise sincerely to the transcriber who took so much care in preparring the transcription.

Two speakers edited the transcriptions we prepared, and those are included in this issue. The remaining speakers are only represented by their abstracts, submitted before the Symposium and published originally in the Symposium brochure., although one speaker also provided some of the images shown with her talk.

I would like to thank Phyllis Turkington, OUGS Membership Secretary and one of the enthusiastic team who organised the Dublin Symposium, for her energetic efforts in chasing-up the speakers and trying to get them to submit brief articles.

We do have numerous papers and book reviews written by OUGS Members. To all of you, I thank you for your patience in waiting for your reports to be published, in some cases waiting nearly a year. Also, thank you to everyone for your help with my numerous queries, requests for missing informtion, help with higher resolution images and other editorial matters. I hope I have done justice to your efforts.

There is another adventure into the geology of Pembrokeshire by John Downes, this time looking at the geology of Skomer Island and the Marloes Peninsula.

Other members have written up their enjoyable and informative geology field trips to various UK and foreign locations: Severnside Branch members to Quebec Province, Canada; East of Scotland members to Sutherland, in north-east Scotland; Severnside to South Wales; and Wessex Branch to Shropshire.

On the Quebec trip, OUGS Newsletter Editor *Lyn Relph found a curious 'blue crystal' in the rock at the harbour town of Saint-Maxime-du-Mont-Louis, on the St Lawrence Seaway. Back in the UK she followed this up with analysis to identify it.*

From the Northumbria Branch we have a series (originally) of articles on Northumbrian geologists. Ranging from the early naturalists of the late 18th century to two enormously influential geologists of the last century — Kingsley Dunham and Stanley Westoll — Karl Egeland-Eriksen has written mini-biographies exploring the development of geological discovery in north-east England.

Lastly, the ever-energetic Duncan Woodcock reports on anthropocene volcano-analogue deposits near Carnforth. He has found a marvellous 'teaching tool' in the slag heaps of the former Carnforth ironworks.

Finally, this issue also includes some of the wonderful photographs taken by members and entered into our annual Moyra Eldridge Photographic Competition 2014: Winners and Highly Commended photographs in each of the categories, plus the Popular Vote winner chosen by the AGM delegates attending that year. The judging at the Moyra Eldridge Competition is, as we all know, anonymous — the judges have no idea when viewing the photographs who the photographers are.

Unprecedented, at the AGM 2014, one photographer — Dr Ian Williamson — almost swept the board! His entries won or were highly commended in every category.

Beginning in 2015 we are changing the regulations for the competition: there will no longer be any entry fee and we will now accept and view all entries as digital photographs. See the latest OUGS Newsletter *for the revised entry guidelines.*

As always, I wish you happy reading.

— David M. Jones, OUGS Journal Editor

Errata

Dear readers,
For Terry Cox's article 'Igneous rock names: a rough guide' in *OUGSJ* 34 (2) please accept the following amendments to the antepenultimate paragraph of the main text:

* delete 'the' in first line before 'questions'
* insert 'cost' between 'analyses' and 'much'

I apologise for these errors. Editor.

OUGS Symposium, Dublin 2013: Recent Developments in Irish Geology

[comprising one article, two edited transcriptions, one abstract with photographs, and six abstracts]

Investigating the causes and consequences of environmental and biological catastrophes in Earth history: lessons from the deep past for our future

Prof. Jenny McElwain

(Plant Palaeobiology and Palaeoecology, School of Botany and Environmental Sciences, U C Dublin)

Abstract [for lecture delivered on 9 August 2013]

The functioning of modern terrestrial ecosystems has been shaped by an evolutionary legacy of four mass extinction events, multiple geologically driven global warming and cooling events, meteorite impacts, the evolution of advanced plant reproduction grades and plant extinction. Studies from the fossil plant record have revealed that global environmental change of a magnitude similar and greater to that predicted by the year 2100 can result in the collapse of terrestrial ecosystems, resulting in high species-level turnover and extinction.

Return of global environmental conditions to pre-excursion norms usually results in a rebound in plant diversity, but with drastically altered ecological composition and evidence for ecosystem instability for hundreds of thousands to millions of years. This presentation will focus on the ecological and evolutionary consequences of a global warming event at the Triassic–Jurassic boundary and the feedback effects of plant adaptation on fire ecology and marine biodiversity.

[Editor's note: The above abstract is that given by Prof. McElwain for the OUGS Dublin Symposium 2013 brochure. Prof. McElwain was unable to write up her lecture as an article for the *OUGS Journal*. The article below is a substitute article sent by Prof. McElwain. This submitted article has been edited for *OUGSJ* house style, to correct a few grammatical and punctuation lapses, to cite all the figures, and to correct a repetition of numbering in the subheadings in the original article.]

Climate change and mass extinction: what can we learn from 200-million-year-old plants?

Jennifer C. McElwain

(Plant Palaeobiology and Palaeoecology, School of Botany and Environmental Sciences, U C Dublin)

Abstract

We are facing unprecedented times in terms of the speed of ongoing climate change. Palaeobotany, the study of fossil plants offers the potential to investigate how levels of carbon dioxide (CO_2) in the Earth's atmosphere — an important greenhouse gas — has changed over the last 400 million years of Earth history. Using a simple inverse relationship between the number of stomata (microscopic breathing pores) on the leaf surface and the concentration of CO_2 in the atmosphere we can reconstruct how CO_2 levels have waxed and waned over time. A long-term view of atmospheric evolution enables us to place the recent >25% rise in CO_2 into a longer-term perspective. Our research at UCD explores critical questions such as, what role have greenhouse gasses played in global warming events in the geological past? More simply put, we can address whether increases in greenhouse gasses in the past resulted in global warming. We are also actively studying whether global warming was wholly, or in part, responsible for any of the five great 'mass extinction events' that punctuated the history of life on Earth. In this paper I will review the long-term record of atmospheric CO_2 from computer modelling and fossil plant evidence and briefly illustrate the effect of past global warming events on natural ecosystems using a database of more than 4,000 fossil plant specimens collected from Triassic- and Jurassic-aged (205 to 195Ma) rocks in East Greenland. I will review fossil plant studies that show that natural global warming events in the past have adversely influenced the ecology and diversity of forest ecosystems and conclude by highlighting the possible implications of this research for the future of Irish ecosystems.

1 Introduction

Over the past 200 years of western industrialization the concentration of the greenhouse gas, CO_2, has increased from a pre-industrial level of ~280 parts per million (ppmV) to 386 ppmV (www.esrl.noaa.gov/gmd/cgg/trends). Fossil fuel use and land-use change — from natural forest to agricultural — are the two primary reasons for this startling trend. If we continue using fossil fuels at the current rate it is anticipated that current CO_2 concentrations will double by the end of this century (Luthi *et al*. 2008). The question is; should we be concerned? CO_2 is not a pollutant gas, it is a natural component of our atmosphere; however, it is a greenhouse gas and because of its heat trapping properties global climate models predict that a doubling of CO_2 will result in a global temperature rise of between 1.5˚ and 4˚C by the year 2100 (Luthi *et al.* 2008). Measurements of the CO_2 content of air bubbles trapped inside Antarctic ice cores have revealed that CO_2 concentrations have waxed and waned through the last two million years of ice age cycles. During cold (glacial) climate phases, CO_2 concentrations as low as ~172 ppmV prevailed, while during the warm phases (interglacials) the CO_2 levels rose to a maximum of 300 ppmV (IPCC 2007) (Fig. 1, *overleaf*).

Thus, ice core records illustrate that the current CO_2 concentration is unprecedented — at no time in the last two million years of Earth history has the level of CO_2 in the atmosphere or

© OUGS ISSN 0143-9472

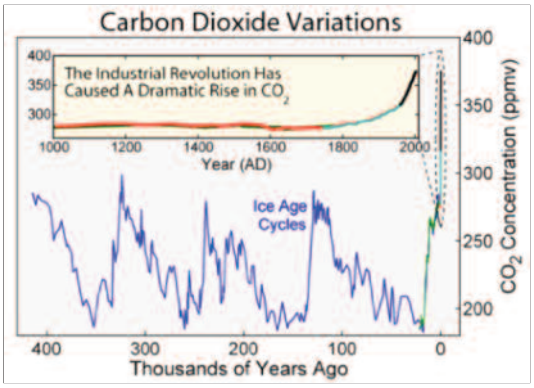

Carbon Dioxide Variations
The Industrial Revolution Has Caused A Dramatic Rise in CO_2
Year (AD)
Ice Age Cycles
CO_2 Concentration (ppmv)
Thousands of Years Ago

Figure 1 Trends in atmospheric CO_2 concentration from ice-core measurements over the last 400,000 years (blue and red) compared with a more detailed record from direct measurements over the last 50 years (black) (image created by Robert A. Rohde — see http://www.globalwarmingart.com/wiki/Image:Carbon_Dioxide_400kyr_Rev_png *for data sources).*

its rate of increase been as high as it is today. This is indeed a sobering comparison; however, if we are heading for a so-called 'greenhouse world' when CO_2 concentrations will rise even further, the ice ages do not serve as the best analogue to understand and project future consequences for the biosphere and our climate system. We need to look further back into 'deep time' when CO_2 levels were as high, and even higher, than they are today. The use of 'CO_2-proxies' is the only mechanism of indirectly estimating how atmospheric CO_2 has fluctuated beyond the direct 800,000-year record provided by analysis of ancient air within ice cores. A CO_2-proxy is any biological, chemical or physical indicator of atmospheric CO_2 concentration.

2 Fossil stomata as indicators of past CO_2

In 1987 a Cambridge botanist, Professor Ian Woodward, observed that the density of stomata on leaf surfaces was inversely correlated with the concentration of atmospheric CO_2 (Fig. 2). He made this observation on dried plant material (herbarium sheets) of native English trees collected over the last hundred years, a time when CO_2 concentrations increased by over 30%. This simple observation has become a powerful tool in paleontological research, as it has enabled us to estimate the CO_2 concentration of past atmospheres by simply counting the frequency of stomata on fossil leaf surfaces. Put more simply, it offers the opportunity to track how atmospheric CO_2 content has changed over the last 400 million years of Earth history!

3 A long-term view of atmospheric CO_2

The results from studies of changes in fossil plant stomatal frequency for different geological intervals have been combined with other proxy-CO_2 sources to build a long-term picture of how atmospheric CO_2 levels have changed over geological time (Fig. 3). This long-term CO_2 record reveals that there have been times in Earth history when [the] CO_2 concentration was much higher than today, such as during the Mesozoic (~200 to 65 million years ago), the so-called age of dinosaurs. There have also been periods of time when atmospheric CO_2 concentrations were significantly lower or equivalent to present levels (such as during the Carboniferous Period ~354 to 200 million years ago).

The most striking feature of these records is that CO_2 levels and global temperatures have been closely coupled over the last 450 million years, with low CO_2 episodes associated with the

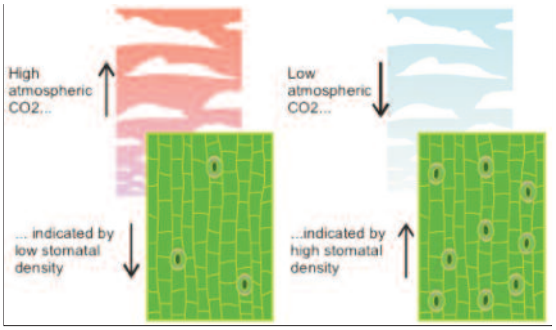


Figure 2 A graphic illustrating how the stomatal proxy method is used to estimate the CO_2 concentration of past atmospheres (University of California Museum of Paleontology's Understanding Evolution — http://evolution.berkeley.edu*).*

formation of extensive polar ice sheets (Royer *et al.* 2004). Conversely, during times of high atmospheric CO_2, the polar latitudes are ice-free. These long-term records of atmospheric composition and climate [can be used] to place more recent historical trends into context (as in Fig. 3). Such an exercise reveals some extremely sobering facts: we learn that the rate of CO_2 rise of our last century — driven by fossil fuel burning and land-use change — is 50 times faster than that associated with any of the best-studied natural global warming events in the geological past.

These records also demonstrate that the current CO_2 concentration is higher than [at] anytime in human evolutionary history, and that by the year 2100 CO_2 levels in the atmosphere will reach levels not seen since the Eocene, some 50 million years ago. Fossil plant evidence from all over the world provides strong evidence that the Eocene was also a time of high global warmth. Mangrove swamps fringed the south coast of Britain. Forests of Dawn Redwoods extended well inside the arctic circle, a place that today is completely treeless owing to the harsh climatic conditions; and forests of Southern Beech were extensive across a completely ice-free Antarctica.

4 Global warming and mass extinction

Our research group at UCD uses the past as a guide for the future. Specifically, we study natural global warming events in the past that were driven by increased levels of greenhouse gasses in the atmosphere, to understand the potential future biological

Figure 3 Changes in atmospheric CO_2 concentration over the last 500 million years based on model estimates (black and grey lines) by Robert Berne (Yale) compared with proxy estimates (in red) compiled by Dana Royer. RCO_2 is a ratio scale of past-to-present CO_2 concentration (redrawn from Royer et al. *2004).*

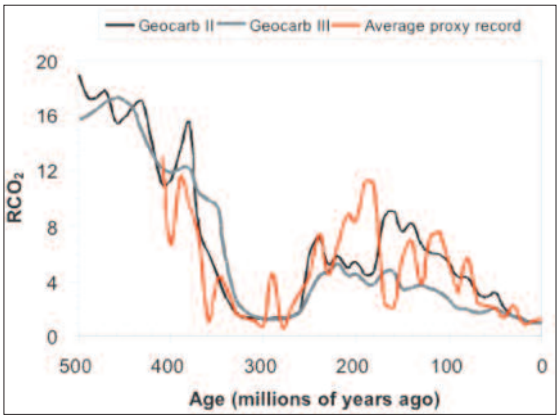


Figure 4 A photo of the treeless tundra vegetation in East Greenland today (top) compared with an artistic reconstruction of what the vegetation looked like 205 million years ago (Late Triassic) (bottom) in the exact same location when global temperatures were 3˚C higher than they are today. Our research has shown that a global warming of 6˚C results in a complete collapse of the Late Triassic ecosystem.

consquences of CO_2-induced global warming. One such event was the so-called Triassic–Jurassic boundary more than 200 million years ago. More than 4,000 fossil plant specimens from Triassic- and Jurassic-aged sediments in East Greenland were collected in 2002 from before, during and after a natural global warming event in order to document the effects on the biodiversity and ecological structure [and] composition of ancient forest ecosystems. This study has revealed (McElwain *et al.* 2007; McElwain and Punyasena 2007) (Fig. 4):

1. catastrophic loss of plant diversity in response to climate change;
2. complete replacement of ecological dominants in response to climate change;
3. 80% extinction of East Greenland species in response to climate change;
4. [and that] certain characteristics increase a species extinction risk, including ecological rarity, reproductive specialization and large leaf size.

We have also hypothesized that the changes in the structure and composition of the ancient forests in East Greenland had a knock-on effect on animals and contributed to the 22% extinction of animal families observed at this time (IPCC 2007).

5 Implications for future Irish ecosystems

Our research typically focuses on times in the deep geological past, when the species make-up of vegetation was very different from that of today. Indeed many of the fossil species we study are extinct. We cannot therefore make specific prediction on the future fate of most species in the Irish vegetation. The power of our method comes from the fact that we can observe general ecological responses to past global-warming events and we can identify certain biological traits that either increase a species risk of extinction or improve a species chance of survival into the future.

One of our most interesting findings from fossil plants studies, and the most relevant in terms of current environmental issues, relates to the sequence of collapse and recovery of vegetation. We have observed that following the collapse of plant communities in response to climate change, the new communities are recruited or built from the existing communities. For example, species that had once played a minor ecological role in Late Triassic communities became the dominant ecological plants in the Jurassic. This observation challenges the prevailing idea that invasive species from other geographical areas will play an important role in future ecosystems responding to future climate change. Instead we predict, based on fossil plant evidence, that future ecosystems, in the most part, will be composed of the same species that are present today, but [that] they will have vastly different ecological roles.

The dominant native Irish forest species of our current ecosystems may be relegated to a lesser ecological role, while the species today [that] are less common may become the dominant forest type. Our analyses of past vegetation responses to climate change also suggest that species that are specialized, in that they require another organism to complete part of their life cycle, will be more prone to going extinct than more generalist species.

6 PÉAC: Programme for Experimental Atmospheres and Climate

We combine our palaeobotanical studies of fossil plant responses to past climate change events with an experimental approach using simulated climate and atmosphere chambers. Plant growth and physiological experiments are currently being carried out at UCD in a new state-of-the-art facility called PÉAC. This facility can simulate any climatic, light or atmospheric environment from the past, present or future (Fig. 5).

Currently we are running a suite of experiments [in which] we have simulated a toxic past atmospheric environment from the Triassic–Jurassic boundary. Analogue Late Triassic plant communities are being subjected to elevated CO_2, SO_2 and temperatures in combination with ambient (21%) and low oxygen concentration (13%) in order to elucidate the key triggering factor for mass plant extinction in the Late Triassic.

Figure 5 PÉAC lab at UCD showing the inside of one of 15 CONVIRON controlled atmosphere and climate chambers. PhD students Amanda Porter and Crissy Evans-Fitzgerald are shown working on Mesozoic plant analogues within one of the controlled PÉAC units.

References

IPCC 2007 *Climate change 2007: The IPCC 4th assessment report*. Cambridge: Cambridge University Press

Luthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola, J.-M., Siegenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura, K., and Stocker, T. F. 2008 'High-resolution carbon dioxide concentration record 650,000–800,000 years before present'. *Nature* **453**, 379–82

McElwain, J. C., Popa, M. E., Hesselbo, S. P., Haworth, M., and Surlyk, F. 2007 'Macroecological responses of terrestrial vegetation to climatic and atmospheric change across the Triassic/Jurassic boundary in East Greenland'. *Paleobiology* **33**, 547–73

McElwain, J. C., and Punyasena, S. 2007 'Mass extinction events and the plant fossil record'. *Trends in Ecology and Evolution* **22**, 548–57

Royer, D. L., Berner, R. A., Montanez, I. P., Tabor, N. J., and Beerling, D. J. 2004 'CO_2 as a primary driver of Phanerozoic climate'. *GSA Today* **14**, 4–10

www.esrl.noaa.gov/gmd/cgg/trends

Recent developments in the Geological Survey of Ireland

Abstract only — please see Editorial

Koen Verbruggan

(Director of the Geological Survey of Ireland)

The Geological Survey of Ireland (GSI), founded in 1845, is Ireland's National Earth Science Agency. It is responsible for providing geological advice and information, and for acquisition of data for this purpose. GSI produces a range of products, including maps, reports and databases; and acts as a knowledge centre and project partner in all aspects of Irish geology. All GSI data is made available freely via the Web. Recent geoscience initiatives supporting infrastructure and planning include mapping Aggregate Potential, Groundwater Vulnerability, Landslide Susceptibility, Urban Geology and Geochemistry, and Quaternary/Glacial Geology. GSI helps lead INFOMAR, Ireland's national marine mapping programme, and is involved in a variety of EU-funded marine projects. Tellus Border [see page 14 — Ed.] is a €5m airborne geophysics and geochemical mapping project that is collecting scientific data on soils, water and rocks across the six border counties [of Northern Ireland and the Republic of Ireland]. Other collaborative projects are undertaken with Local Authority or EU partnership across all areas of geoscience, but currently [at the time of the lecture] are focused on marine, groundwater, geoheritage and earth observation. A national geoscience research award scheme, administered by the GSI, has provided more than €10m over a seven-year period to raise capacity in geoscience research on the island of Ireland.

Evolution of the first tetrapods — a conflict of evidence

Abstract only — please see Editorial

Prof. Ken Higgs

(Emeritus Professor, School of Biological, Earth and Environmental Sciences, U C Cork)

The colonization of land by vertebrate animals was a momentous event in the history of life. Amphibians evolved from Elpistostegid fish and the earliest amphibians are called tetrapods. There is conflicting fossil evidence of when, where and in what environment the first tetrapods evolved. The evidence from skeletal remains supports the traditional view of vertebrate palaeontologists that the fish–tetrapod transition took place in the Upper Devonian Period, and that it occurred in a continental freshwater setting. However, recent evidence from tetrapod footprints found in Middle Devonian rocks found in Ireland and in Poland indicate that tetrapods evolved much earlier (possibly in the late Lower Devonian). Additionally, the Polish footprints suggest that the fish–tetrapod transition took place in a marine–intertidal environment rather than in a riverine setting. The details of new tetrapod footprint finds from Valentia Island in south-west Ireland and from Zachelmie in southern Poland [were] presented and their implications discussed.

The Irish National Seismic Network and CTBTO monitoring — a wave of scientific opportunity

Tom Blake

(Director of the Irish National Seismic Network (INSN), Dublin Institute for Advanced Studies)

Abstract

The Irish National Seismic Network has undergone significant expansion and development in recent times. There are now six real-time, permanent seismic stations throughout Ireland monitoring local, regional and worldwide seismic activity. These data are shared with research colleagues throughout the world and provide an opportunity for international scientific cooperation between the Dublin Institute for Advanced Studies (DIAS) and other institutions. The real-time recording of seismic data means that potentially threatening earthquakes can be analysed quickly to assess their characteristics, as well as provide research material for the study of the Earth's deep interior.

Owing to public interest, DIAS has developed an Outreach Programme for schools, geo-parks and universities. It comprises an initiation into seismology for students and for the local installation of a seismometer, and helps students to visualize seismology and to observe the recording of earthquakes. There is a heightened awareness of the threat posed by tsunamogenic earthquakes as a result of the Tokohu, Japan and Banda Aceh, Indonesia events. What lessons, if any, need to be learned by countries in the circum-Atlantic region are discussed.

The designation of the School of Cosmic Physics as the National Data Center of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) and the development of the CTBTO's international monitoring system provide an important opportunity for strengthening cooperation by Irish scientists and academics with the wider international scientific community.

[Editor's note: What follows is the author's summary of the transcript of his lecture (prepared for him by an OUGS volunteer transcriber), edited by the *OUGSJ* Ed. as indicated in square brackets. Unfortunately, the author did not provide any captions for his figures, which are here reproduced at the maximum sizes possible, given the resolution quality of the files provided.]

© OUGS ISSN 0143-9472

At the recent Open University Symposium at Dublin City University, I spoke about the following topics:

1. The National Seismic Network
2. Seismology in Schools Programme, DIAS outreach programme
3. The National Data Centre, Comprehensive Nuclear Test-Ban Treaty Organisation (CTBTO)
4. NEAMTWG

The Dublin Institute for Advanced Studies was formed in 1940 and today consists of three constituent schools: The School [of] Cosmic Physics, The School of Theoretical Physics and The School of Celtic Studies.

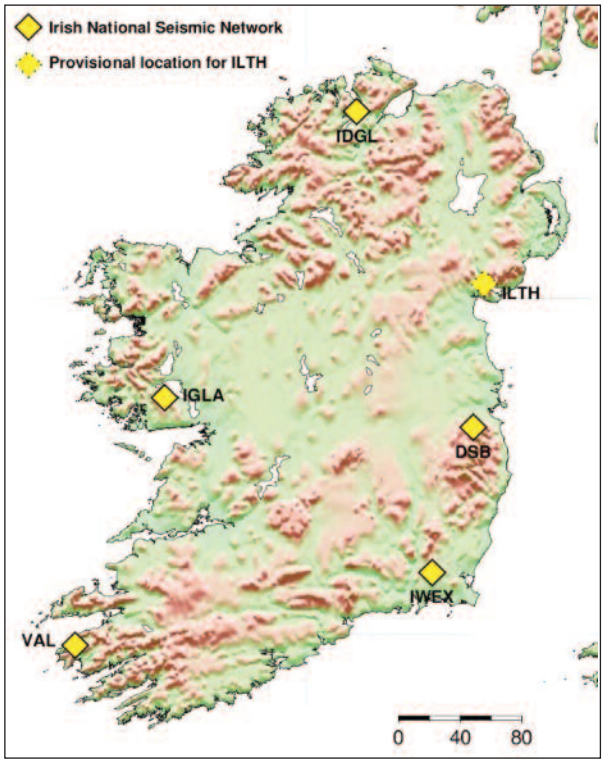
The institute itself is a graduate facility where people come to study [for] Masters degrees, for PhDs, or for post-Doctoral research, by affiliation already through a University, such as Trinity, UCD, Galway or Cork.

Irish National Seismic Network (INSN)

The Irish National Seismic Network is part of the Global Seismic Network of permanent seismic stations around the world that contribute data in near real-time. In the current distribution of stations in Ireland, we have five in operation: Valentia, Galway, Donegal, Wexford and Dublin Mountains, and the sixth and final one will be County Louth, which [at the time of this talk] is in construction (Fig. 1).

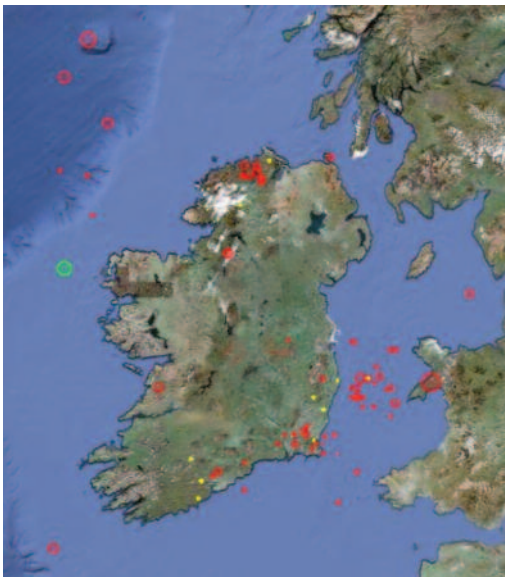
We don't have very strong earthquakes in Ireland, but we do get earthquakes that range in magnitude 0.5 up to Mag 5.4 [assumed to be on the Richter scale — Ed.], which is the largest that we [have] ever felt. It occurred off the Lleyn Peninsula, North Wales. On Figure 2 the red dots represent events that have been plotted since 1980 [Blake pointed out 'a very nice event' off the coast of Mayo, of magnitude of 4.2]. More recently we have had a spate of earthquakes in the Irish Sea ranging between 2.6 and 3.8, associated with the fault in the Irish Sea. [There are] two significant areas of interest, one is in the North West in Donegal, probably more influenced by the large structural features that [are connected to] the complex structural geology of Scotland; and [a second area of interest] in south-east Ireland, [where] we have another area of seismic activity, usually in the range of magnitude 2.

Figure 1 The Irish National Seismic Network.



Blake next talked about the anatomy of seimsograms, and the wave properties associated with S-waves and Surface Waves. There are the two things to remember about the anatomy of a seismogram, you have the P-Waves at 8 km/s, [representing] push-pull, parallel motion; [and] Shear Waves at right-angles to the direction of motion, travelling much slower. And then [there are] Surface Waves — as the name suggests, they don't go through the body of the Earth, they go over [its] surface. Surface Waves travel much [more] slowly, [only] *c.* 3.5 km/s to 4.00km/s.

Figure 2 Irish earthquakes registered since 1980.



Seismology in Schools Programme, or Seismeolaíocht Sa Scoil

The Seismology in Schools Programme, or Seismeolaíocht Sa Scoil as we say in Irish, is a DIAS Outreach programme for second-level students. The British Geological Survey developed this Horizontal Component Seismometer (Fig. 3, *opposite*). The British Geological Survey (BGS) and the Incorporated Research Institutions for Seismology (IRIS) got together to promote [its use]. The Horizontal Component Seismometer is a reasonable teaching tool, but a very accurate one as well. The IRIS developed the software, [while] the BGS and University of Middlesex developed the hardware and plugged the [instrument] into a computer. [With it an operator is] able to record earthquakes of magnitude 6, [even] from the other side of the world.

The reason [that use of the instrument has been] successful in Ireland is because we have incorporated the Association for Teachers Education training centres in Ireland, [which] saw the benefit of [teaching seismology] in schools, and [joined] us as a funding partner. We now have more than 60 schools all over Ireland operating seismometers in this programme.

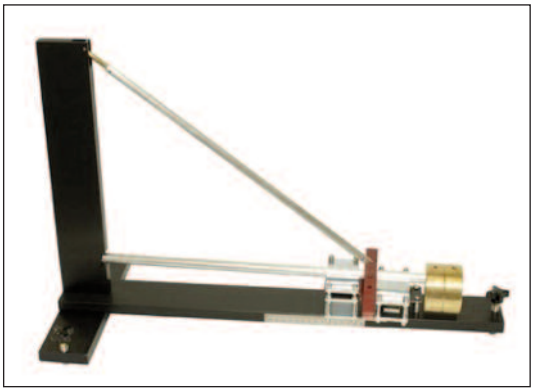


Figure 3 BGS Horizontal Component Seismometer.

Robert Mallet, Irishman and Father of Controlled Source Seismology

Robert Mallet, [is known as the] Father of Controlled Source Seismology (Fig. 4). Using explosives on Killiney Beach in south Dublin, he showed that the energy associated with explosions changes as it goes through sand, as it goes through rock, [and] as it goes through different kinds of [rock]. He was the first person to say that earthquakes [were not] wrath from God for our sins, [but] are natural phenomenon, [and] can be explained by something as simple as Snell's Law, which deals with reflection and refraction through different media.

[Mallet] began to develop a strong interest in earthquakes, in fact [in] the whole [subject of] seismology. His seismic risk and hazard research was exemplary and the first of its kind. [For example] he took a [special] interest in the Great Neapolitan earthquake of 1857. The Royal Society of London [gave him] a grant [for] travel [and] research, underwritten by [his two friends and fellow members] Charles Lyell and Charles Darwin. [Trained as an engineer], if you walk along the rails of Trinity College you will see his name underneath the rails — Robert Jnr Mallet — for he ran a[n] Iron Foundry Plant as his day job.

Figure 4 Robert Mallet, Father of Controlled Source Seismology.

NEAMTWG

NEAMTWG [stands for] the North East Atlantic and Mediterranean Tsunami Warning Group, [formed to monitor earthquakes and tsunamis that occur in, or could affect, the region]. [For example on] November 1st, 1755 there was [a] massive submarine earthquake off the coast of Lisbon [that] was felt [as far north as] Cork. And later on [the same] day a body of water is reported to have arrived and the south coast of Ireland inundated with 15ft-high waves. [Because of this and other such] events in the past we need to take [them] into account if we are going to look after [Irish] harbours [and] their hinterlands.

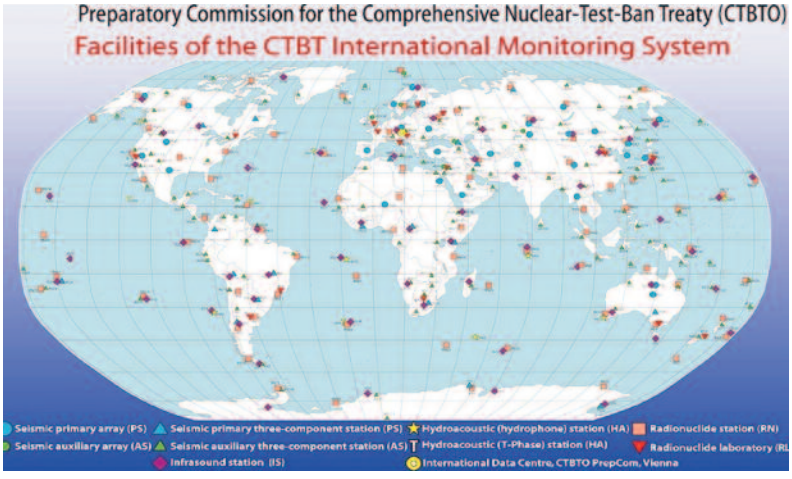
National Data Centre (NDC) Comprehensive Nuclear Test-Ban Treaty Organisation (CTBTO)

The Dublin Institute for Advanced Studies [DIAS] [and its] National Data Centre (NDC) — of which I am the head — have been designated by the Comprehensive Nuclear Test-Ban Treaty Organisation (CTBTO) [as a centre for data gathering and storage] (Fig. 5). The CTBTO uses four different scientific methodologies [to verify] a nuclear blast: radionuclide, hydro-acoustics, infra-sound and seismology monitoring. [It is in recognition of] our seismological expertise that we have been the designated as the National Data Centre [in Ireland].

Any seismic event — whether it is a quarry blast by a local farmer, a small local earthquake or a nuclear blast — will generate a seismic signal. Part of our responsibility is to use our seismic network records to record and analyse these.

[In conclusion] I hope I have given you some idea of the extent of [the] seismology [research] we do at DIAS [and the records we keep]. My message [is] that people will believe that science is relevant to their own lives when this reality is reflected and reinforced by what we see and read in the media.

Figure 5 Comprehensive Nuclear Test-Ban Treaty stations worldwide.


Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty (CTBTO)
Facilities of the CTBT International Monitoring System
Seismic primary array (PS)
Seismic primary three-component station (PS)
Hydroacoustic (hydrophone) station (HA)
Radionuclide station (RN)
Seismic auxiliary array (AS)
Seismic auxiliary three-component station (AS)
Hydroacoustic (T-Phase) station (HA)
Infrasound station (IS)
International Data Centre, CTBTO PrepCom, Vienna

New perspectives on the post-Caledonian faulting of onshore Ireland

Abstract only — please see Editorial

Prof. John Walsh

(Joint Director, Fault Analysis Group, School of Geological Sciences, U C Dublin)

A long-standing issue in the structural analysis of onshore Ireland is the paucity of post-Carboniferous rocks over much of the island and the associated difficulty of defining the structural evolution of the last 300Ma. This problem is sometimes compounded by the perception that certain rocks have structures of a particular age and type: [for example,] while deformation in Lower Palaeozoic rocks is most often ascribed a Caledonian or older age, deformation of Devono-Carboniferous rocks is often considered to be no older than Variscan [date] (i.e. end-Carboniferous). Using newly acquired data from both onshore and offshore Ireland, [Prof. Walsh's] talk describe[d] the prolonged history of faulting in Ireland from Caledonian through to Oligocene [date] (20Ma), and shows that post-Caledonian faulting is characterised by multiple reactivation of faults, [this] younger fault activity having a profound impact on the geology of much older rocks and on fluid flow within them.

The Navan ore body, Ireland: a world-class carbonate-hosted Zn-Pb deposit

Abstract only — please see Editorial

Dr John Ashton

(Chief Mine/Exploration Geologist, Boliden Tara Mines)

*Central Ireland contains a world-class carbonate-hosted Zn-Pb province, currently with two mines contributing >60% of western European zinc production. The mine is operated by Boliden Tara Mines Limited, which currently extracts 2.5Mtpa of ore from Europe's largest zinc mine. The ore body comprises strata-bound sulphide lenses hosted by Lower Carboniferous shallow-water carbonates of Courceyan to Chadian age (Early Mississippian [*c. *359–323Ma]). The deposit is focused along an early ENE-trending, NW-dipping, extensional fault system. The ore body has been the subject of numerous and diverse geological, geochemical and geophysical investigations since its discovery in 1970. Fluid inclusions reveal a large spread in both fluid salinity and temperature consistent with mixing between shallow-sourced hypersaline brines and deep-sourced, less saline hydrothermal fluids. The bulk signature of the deposit indicates that >90% of the sulphide was derived through bacteriogenic reduction of seawater sulphate. Derivation from Lower Carboniferous sea water is inferred. Mixing of the sulphide-rich surface brines with the basement-sourced, metal-bearing fluids was the key process in ore deposition and may have encouraged bacterial activity during minerlization. Thus, the major lower microbiological factors formed an exceedingly efficient trap mechanism that created the world-class, carbonate-hosted Zn-Pb deposit at Navan. [Ed. — Dr Ashton's lecture reviewed this work].*

Tectonic and magmatic controls on hydrothermal venting, Mid-Atlantic Ridge: Moytirra

Abstract only — please see Editorial

Prof. Andy Wheeler

(Chair of Geology, School of Biological, Earth and Environmental Sciences, U C Cork)

An Irish-led scientific expedition (VENTuRE) aboard the national research vessel RV Celtic Explorer *with the* Holland 1 *Remotely Operated Vehicle (ROV) discovered a previously uncharted field of hydrothermal vents along the Mid-Atlantic Ridge in August 2011. At 3,000m water depth, this is the first deep-sea vent field known on the Mid-Atlantic Ridge north of the Azores and south of Iceland.*

Moytirra is compact, with a high flux of hydrothermal fluids and consists of 15m tall metal sulphide chimneys at the base of a 200m fault scarp. It is basalt-hosted, with tectonic controls dominating the hydrothermal stockworks fed by an off-axis magma source. High-resolution multibeam maps and ROV observations suggest chimney complexes of different ages and venting activity. The samples show significant banded concentrations of metals, including zinc, copper, arsenic, molybdenum and iron. The site is also colonised by vent-adapted fauna, [for which] larval dispersal and isolation seem to have a strong control on community structure.

[Editor's note: We prepared a transcription of Prof. Wheeler's lecture at the Dublin Symposium, when he accepted our offer to do so. Unfortunately, however, Prof. Wheeler said he did not have time to write up his symposium talk for the *OUGSJ* from this transcription. Interested readers may wish to pursue his research at a link that he has provided, copied and pasted from his e-mail:
http://onlinelibrary.wiley.com/doi/10.1002/ggge.20243/abstract;jsessionid=276B96798C04BB643E4A4852FCA033F3.f04t04?deniedAccessCustomisedMessage=&userIsAuthenticated=false]

Recent developments in Irish offshore oil and gas exploration

John O'Sullivan

(Technical Director Providence Resources plc)

Abstract

Notwithstanding a relatively poor historical commercial success record, there has been a recent significant increase in offshore Irish oil and gas exploration. This has been stimulated principally by a number of non-geological macro-drivers, such as new technology, higher oil and gas prices, and recently built gas pipeline infrastructure, as well by more favourable fiscal terms. Exploration companies are not only developing novel exploration concepts, but are also re-evaluating historical, dormant oil and gas macro-drivers and looking at the various enabling facets and technologies pertinent to offshore exploration. A number of field and prospect case studies [are] presented, ranging from the shallow waters offshore Dublin in the Irish Sea to the ultra-deep reaches of the southern Porcupine Basin.

Introduction

Providence Resources (PR) is the leading diversified oil and gas exploration and appraisal company active [for] offshore Ireland. In recent years, there has been a significant increase in its activity, driven primarily by:

- pricing — current sustained higher oil and gas prices;
- new technology, both surface and subsurface;
- revised fiscal terms designed to attract foreign direct investment;
- and infrastructure — recently installed gas infrastructure enabling better market access.

Numerous oil and gas discoveries have been made off the coast of Ireland in the past 40 years, but only four have reached commercial development, all of them gas fields. Existing oil discoveries are either small accumulations of high-quality oil or large fields containing either waxy or heavy oil, which historically would have been difficult and economically challenging to develop owing to a lack of appropriate technologies, lower oil prices and higher extraction costs.

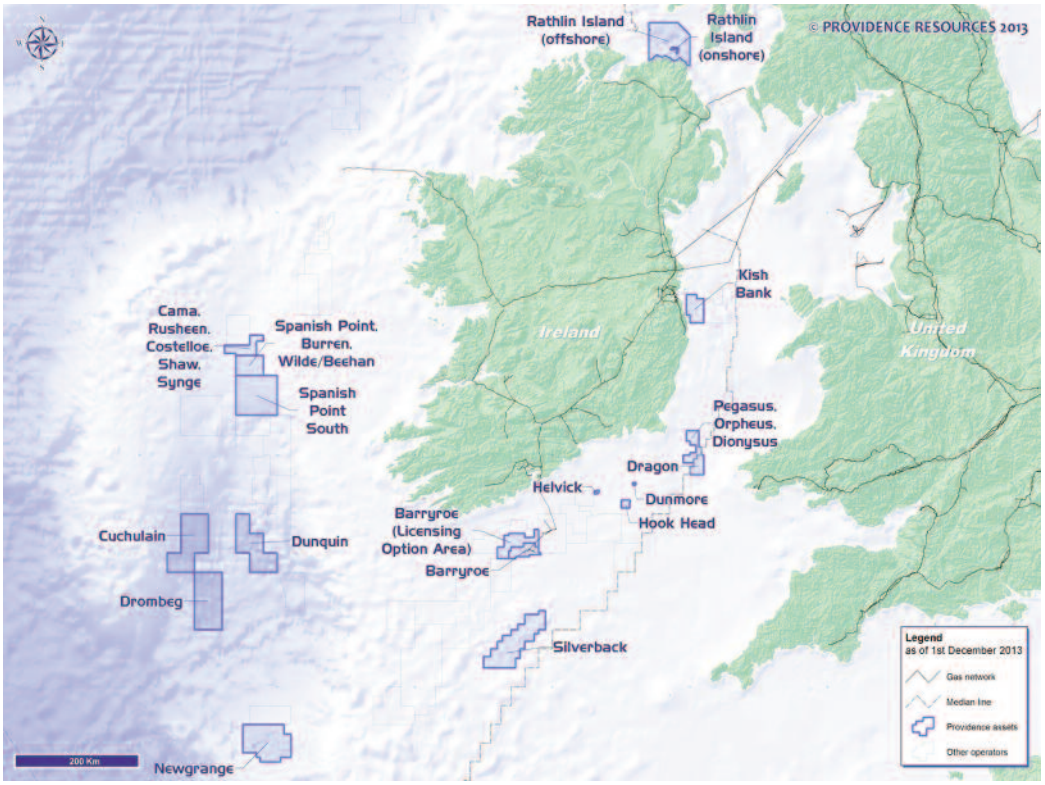
Providence's exploration strategy

Providence has been active in Irish offshore oil and gas exploration through various corporate guises for the past 30 years. The company's corporate strategy is based on 'first-mover' advantage, which leverages internally generated intellectual capital, such as innovative geological modelling or the application of new geophysical technology, to a particular area or project. Typically, these offshore projects have a four- to five-year life cycle, spanning concept inception to proofing with the drill-bit. The company is currently the most diversified acreage holder, being active in eight sedimentary basins around Ireland (Fig. 1).

In 2011, Providence embarked on an offshore multi-basin, multi-prospect drilling programme, the second well in its programme on the Dunquin North exploration prospect having recently been completed. The total programme is expected to cost *c*. $500 million. The multi-basin approach was designed to mitigate risk through a portfolio approach. Providence generally partners with major oil companies as a method of external project validation. The company currently works with world-class companies such as ExxonMobil, Repsol, ENI and PETRONAS on projects that were organically generated within Providence.

The multi-basin drilling programme is focussed primarily on oil appraisal and development projects. This involves the drilling of wells on structures that have been previously drilled and that have demonstrated oil flows to the surface. In general, these projects have also been surveyed using 3D seismic techniques, which can greatly improve the imaging of the sub-surface oil-bearing reservoir zones. The first well in the programme, Barryroe, was such an oil appraisal project drilled *c*. 50km off the Cork coast in 2011–12. It caused a major refocus of the industry to southern Ireland. In addition to appraisal projects, the programme also includes a number of exploration projects of higher risk, as the presence of oil or gas has yet to be confirmed. Generally, these projects are characterised by having a lower-density,

Figure 1 Location map of Providence Resources offshore exploration blocks (PR).



© OUGS ISSN 0143-9472

2D seismic reflection profile data, with limited, if any, offset well control. The Dunquin North prospect is an example of such a project, drilled in the deep waters of the southern Porcupine Basin in 2013.

Oil and gas fundamentals

Fundamentally, the global population is consuming more fossil fuels; and as population increases — it is presently double what it was 50 years ago — the projected growth in demand for oil and gas is set to increase. While non-fossil fuel energy sources are making an increasingly important contribution to the overall global energy budget, the demand for oil and gas is still set to increase. In addition, the price of oil and gas continues to rise in long-term trends owing to the dynamics of supply and demand. This state of affairs is causing companies to re-evaluate areas such as offshore Ireland, not previously considered to be highly-prospective, and to re-evaluate them through the lens of new technology, higher oil prices etc.

Irish offshore hydrocarbon prospectivity exists in reservoirs of Carboniferous to Cenozoic age. As in much of north-west Europe, the late Carboniferous of Ireland was dominated by significant coal deposition, which forms important source rocks for gas fields such as Corrib, off the west coast of Ireland. The overlying desert sandstones of the Permo–Triassic are important potential reservoir zones, with the Lower Triassic Sherwood Sandstone Group comprising the main reservoir at Corrib. The overlying Middle–Late Jurassic sandstones are important reservoirs in the nearby North Sea, having been deposited as delta systems and deep-sea fans providing the reservoir for the Spanish Point gas-condensate discovery off the west coast of Ireland. The sandstones deposited in overlying transgressive systems tracts of Lower Cretaceous date provide the main reservoirs of the Barryroe oil field and giant Kinsale Head gas field off the south coast of Ireland. In a mega-regional context, Ireland's Mesozoic conjugate margin is part of the eastern Canadian margin (Fig. 2). Plate reconstruction studies have placed the Irish Atlantic Margin between the Grand Banks of offshore Newfoundland and the west coast of Scotland, both of which host giant oil accumulations.

Viable petroleum systems are required to meet the following five key conditions:

1. source — organic material that has been exposed to high pressure and temperature;
2. reservoir — porous material that acts as a host for any hydrocarbon generated;
3. seal — impermeable material that acts as seal for any hydrocarbons within a reservoir;
4. trap — a subsurface morphology that entraps oil and gas;
5. and migration/timing — a pathway between the source and the reservoir must be present at the time the source actively expels hydrocarbons with a reservoir seal in place.

Petroleum systems analysis involves the mapping of these elements in order to understand locations where they co-exist, and are thus the areas with the highest probability of discovery. Multi-domain data are used in petroleum systems analysis such as potential field, regional 2D seismic reflection data, high-resolution 3D seismic reflection data, and offset well log and core data, together with outcrops if applicable. Multiplying the risk of occurrence of the various elements of the petroleum system provides the Geological Probability of Success (GPoS) — that is, the probability of making a hydrocarbon discovery. In the exploration phase, most wells have a GPoS of <40% (less than 1 in 2). In addition, the discovery of hydrocarbons does not necessarily mean an oilfield development will follow, as the find may contain a sub-commercial volume of hydrocarbons — of technical interest but of neglible commercial value.

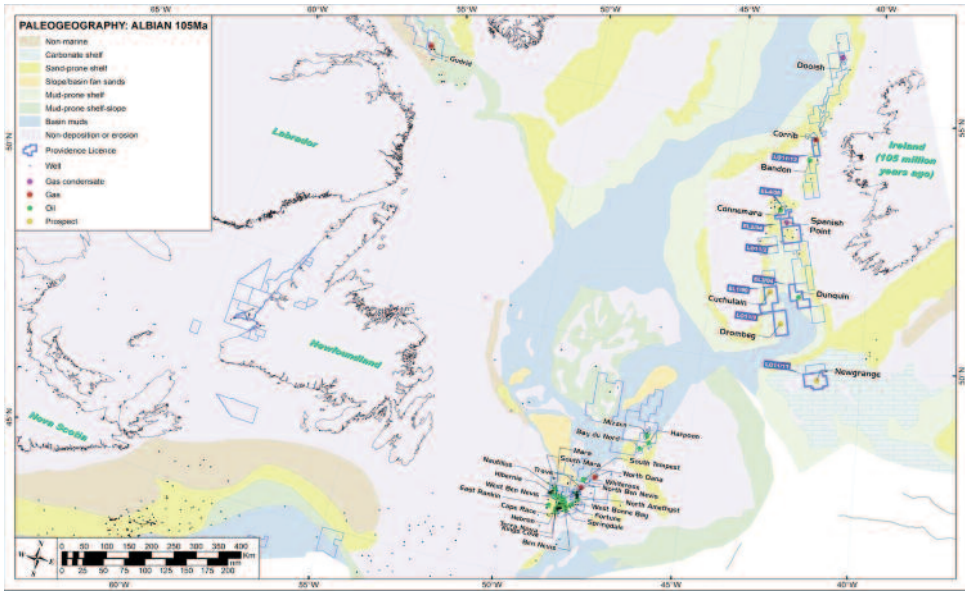
Key elements for a commercially viable hydrocarbon discovery include the following:

- resource size — total recoverable volume of oil and/or gas;
- the cost of development — CAPEX;
- the operating costs — OPEX;
- and the revenues — oil/gas price assumptions, fiscal terms.

Wells can be drilled that are vertical, inclined or even horizontal. The recent Dunquin North exploration well off the south-west coast of Ireland was drilled to a depth of 5km in *c.* 1,600m of water. In the US Gulf of Mexico, fields are producing from depths of 9,000–10,000m. At such depths, pressures and temperatures are high, which introduces issues about how materials perform in such environments. The drilling of an exploration well begins with a large internal well bore size, which is cased with a steel pipe and cement at a certain depth to maintain stability. The well is then drilled in sections and successively cased at various depths leading to a much smaller internal diameter at depth than the initial well bore size. Deep-water drilling rigs cost about $1–1.25 million per day to operate, so programme efficiency is a key focus in these operations.

Offshore Ireland is considered to be highly prospective, but under-explored. A 2005 audit, carried out by the Irish government's Department of Energy, Communications and Natural Resources, indicated a 'yet-to-find' reserve potential of about ten billion barrels of oil-equivalent. This number is on par with the UK Atlantic Margin and North

Figure 2 Map of North Atlantic conjugate margins Albian paleogeography (after PAD-PIP).



Sea remaining reserves, and so ranks as being somewhere of interest for the exploration industry. So far, only about 130 exploration wells have been drilled offshore Ireland. A high proportion of these have intersected hydrocarbons, but there have been just four commercial gas developments. In the deep-water west coast, 43 exploration wells have been drilled with five significant oil and gas discoveries, so the discovery ratio is *c.* 12%. This success ratio isn't bad, given that most of these wells were drilled many years ago, in the 1970s and 1980s, and were based on poor seismic imaging technology, drilling limitations and other factors.

Offshore Ireland, in general, and the Atlantic Margin, in particular, experience harsh offshore met-ocean conditions, which can cause significant rig down-time and add further costs and complexity to offshore operations. Globally, there is limited availability of high-cost, deep-water drilling rigs, so for instance, the rig used to drill the recent Dunquin North exploration well had to be brought from Liberia, off West Africa.

New state-of-the-art 3D seismic data, which provide high-resolution images of the subsurface rock formations, have become key to mitigating risk in the light of ever increasing well costs. In a marine environment, this involves the use of a large vessel (Fig. 3), which tows long streamers of pressure sensitive hydrophones, generally 5–10km long. The vessel emits sound waves into the seabed and the recorded echoes of these waves from the rock layers are detected by the hydrophones arrays. The geologist maps these processed reflections, and when integrated with offset well control and/or potential field data, they can be used to build up a subsurface model. These models can then be used to determine the future hydrocarbon potential and associated risks and costs involved in drilling within an area.

Figure 3 MV Polarcus Amani *state of the art 3D seismic vessel which has been to used to acquire much of the recent 3D seismic data in the Porcupine Basin, offshore Ireland (Polarcus).*

Barryroe Oil Field, North Celtic Sea Basin (Providence 80%, Operator)

The Barryroe oilfield lies off the south coast of Ireland and is adjacent to the giant Kinsale Head gas field, which has been producing for about 35 years. It is *c*. 70km offshore and lies in *c*. 100m water depth covering an area of *c.* 250sq km. Barryroe was originally discovered in 1973–4 by ExxonMobil and Marathon, who drilled a further four wells between 1974 and 1990. The field was never developed at the time owing to lower oil prices, poorer technology, less favourable fiscal terms and other factors.

Figure 4 Barryroe oil field 48-24-10z appraisal well testing operations (PR).

In 2011, Providence Resources acquired a new 3D seismic survey over the field in order to map the full extent of the oil accumulation. In 2012–13, a new appraisal well was drilled in order to collect a modern suite of information in relation to the oil-bearing strata, fluids and reservoir productivity. The main basal Wealden reservoir was confirmed to be a high productivity, braid–plain deposit. While the Barryroe crude is waxy, high-pour-point oil, it is highly mobile in the reservoir owing to the *in situ* heat, and is a premium-grade oil that would be expected to trade at a premium to the Brent benchmark.

Given the very temperature-sensitive nature of the Barryroe oil, heat management was a key focus during the drilling of the appraisal well, as the oils effectively freeze, or reach their pour-point at *c.* 80˚F (*c*. 25.5˚C). In the subsurface, however, the oil is at 150˚F (*c*. 65.6˚C), which keeps the oil moving through the reservoir. As the oil comes up the well it cools and wax crystals form, so it is crucial to keep the oil above a certain temperature (the pour-point) if the oils are to continue to flow.

To keep the oils hot in the Barryroe appraisal well, some interesting technology called vacuum-insulated tubing was deployed. Effectively, the tubing in the upper most 800m of the well, which is usually the coolest, comprised a 5in (127mm) pipe-in-pipe system, one inside the other, and a vacuum between the two. This was effectively like a giant 800m long thermos flask to maintain the heat within the oil. Once the oil reaches the surface, it is relatively easy to manage with heat exchangers and insulation. The Barryroe well produced oil in excess of 3,500 BOPD (Fig. 4), which was much greater than had been expected or had been previously achieved by ExxonMobil or Marathon (whose production was *c.* 1,600 BOPD). In addition, there was also no evidence of significant wax precipitation anywhere in the production system, confirming that the heat management approach employed was appropriate.

Final analysis of the well and 3D seismic data confirmed a mid-case recoverable oil volume in excess of 300 million barrels from the two main tested reservoir zones.

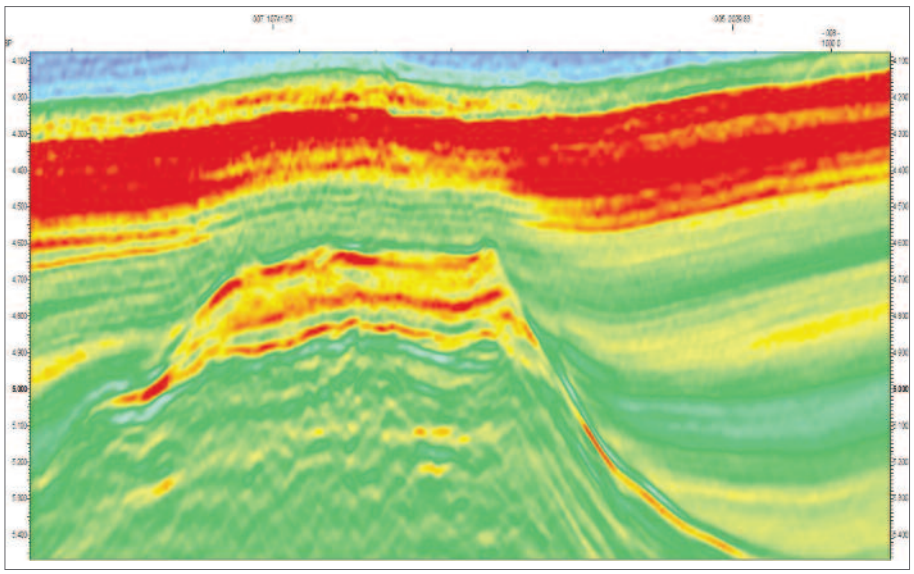


Figure 5 Seismic reflection impedance display of Dunquin carbonate build-up on Porcupine Median Volcanic Ridge (red is high impedance; PR).

Dunquin oil prospect, southern Porcupine Basin (Providence 16%, non-Operator)

The Dunquin exploration prospect is in the southern Porcupine Basin, *c.* 200km off the west coast of Ireland, at *c.* 1,600m water depth. The target comprises a large mid-basin ridge system, which hosts two seismically identified Lower Cretaceous carbonate accumulations (Fig. 5). This location is a new reservoir-play system for offshore Ireland and given the undrilled nature of this vast deep-water basin, the well was considered to be of very high risk with a *c.* 16% GPoS — that's an 84% chance of failure! However, such Lower Cretaceous carbonates are prolific oil and gas reservoirs in the Gulf of Mexico, as well as in the Persian Gulf.

Published palaeogeographic models from this period locate the southern Porcupine Basin at the northern limit of Lower Cretaceous oil- and gas-bearing carbonate platforms globally. In addition, palaeoclimatic modelling indicates a north-easterly trade-wind in the southern Porcupine Basin, which is consistent with the mapped morphology of the interpreted carbonate accumulations. The well, which was situated on the northern-most feature, was drilled using the giant deep-water Erik Raude rig (Fig. 6) and cost *c.* $200 million. The well encountered 250m of massive, high-porosity carbonate reservoir with a residual oil column at the upper *c.* 50m. While this well does not itself appear to be commercially viable, the drilling result bodes well for future exploration of the basin, as it has proved the presence of an active oil source. In addition, the new and novel carbonate reservoir-play paradigm was also correctly predicted from seismic data.

Figure 6 Eirik Raude semi-submersible deep-water drilling unit (Ocean Rig).

Drombeg oil exploration prospect, southern Porcupine Basin (Providence 80%, Operator)

Adjacent to the Dunquin prospect, the Drombeg exploration-play is an extensive stratigraphic area of Lower Cretaceous seismic reflection amplitude anomaly (Fig. 7, *opposite*). The anomaly has been interpreted to be a deep-water turbidite fan deposit and appears to be related to a deeply buried rotated fault block, in which the seismic image shows a fluid escape feature at its crest. The amplitude anomaly has been modelled by IKON Science (a specialist in this area) to be consistent with a 300ft thick (91.4m) hydrocarbon-bearing sandstone interval. This is an exciting and appealing prospect, given its proximity to the Dunquin North well, where oil entrapment has now been confirmed in Lower Cretaceous carbonates. The prospect is in 2.5km of water, which means that the drilling costs will be high, although fields in similar water depths are currently producing oil and gas elsewhere in the world.

Spanish Point gas condensate discovery, northern Porcupine Basin (Providence 32%, non-Operator)

The Spanish Point gas condensate discovery is trapped in a Brent-type rotated fault block play. Drilling was [at the time of the lecture] planned for summer 2014. The original discovery well, which was drilled in 1981 (Fig. 8, *opposite*), discovered a gas-condensate accumulation in deep-water turbidite sands of Upper Jurassic Volgian age. The well encountered *c.* 300m of hydrocarbon-bearing sands, but missed the very top of the fault block because of the poor-quality data used in well planning at the time. The new appraisal well, which is being operated by Cairn Energy, is planned to drill a full stratigraphic section *c.* 2km north-east of the original well. Spanish Point is thought to contain up to *c.* 200 million barrels of oil-equivalent recoverable.

The Rathlin Basin, Northern Ireland (Providence 100%, Operator)

A recent well drilled in Co. Antrim, onshore Northern Ireland discovered oil in a Namurian deltaic sandstone reservoir. Providence subsequently licensed the offshore part of the basin and acquired Full Tensor Gradiometry (FTG) potential field data as well as reprocessing some existing 2D seismic reflection profile data. These data demonstrate significant oil potential in the basin. Given that part of the basin is onshore and exhumed along the basin margin faults, it is possible to go and look at the target

reservoir and oil source rocks in outcrop. On the offshore island of Rathlin, the Cenozoic basalt, which is incised into the Chalk, is spectacular in cliff sections along the southern part of the island. At Murlough Bay along the Antrim coast there are spectacular outcrops of the deeper succession of Carboniferous to Triassic age. At this location, the Coal Measures of the Namurian, with inter-bedded sandstones, are well developed (Fig. 9), potentially providing important insight into source and reservoir relationships within the adjacent buried basin. These sections can be logged and evaluated for gas- or oil-sourcing potential based on their geochemical signatures. Available offshore seismic data show many different types of potential trapping morphologies for hydrocarbons such as inversion-induced flower structures and rollover anticlines.

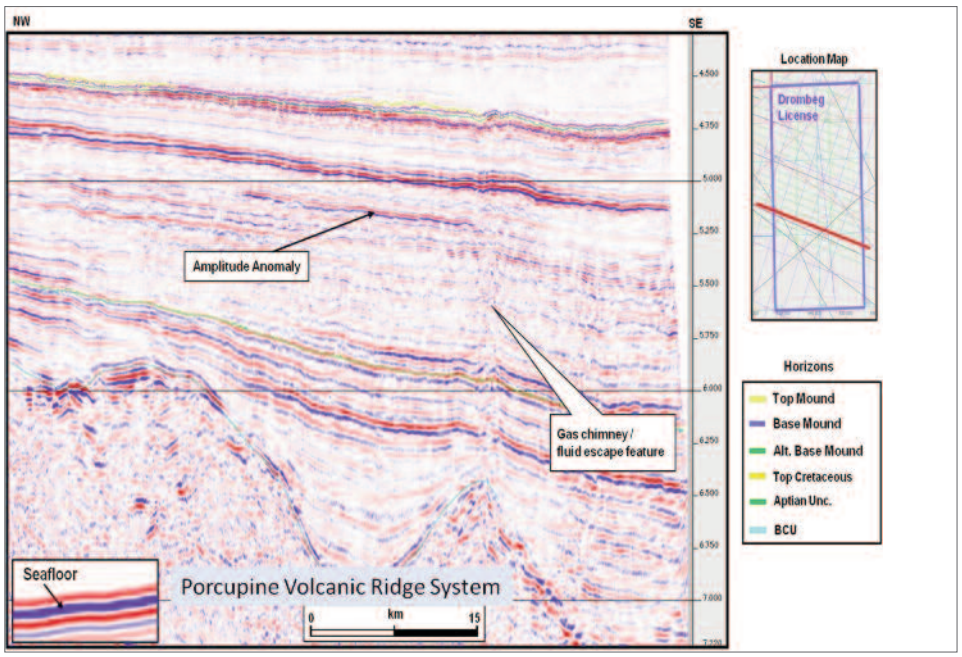


Figure 7 Lower Cretaceous Drombeg prospect seismic amplitude anomaly, southern Porcupine Basin, offshore Ireland (PR).

Summary

The Irish offshore is a vastly underexplored region with huge hydrocarbon exploration resource potential. Development of a viable offshore industry is, however, all about drilling wells, and Providence has been the leading light in this regard for the past number of years. The government has recently embarked on a major regional 2D seismic reflection survey across many of the previously unmapped areas of the offshore and in addition, a number of private companies are acquiring large 2D and 3D seismic surveys. The future is bright for the Irish offshore, and following the Dunquin North well, the evidence of oil generation and entrapment in the vast and unexplored southern Porcupine Basin means that the exploration vector along the Irish Atlantic Margin can only be in the ascendant.

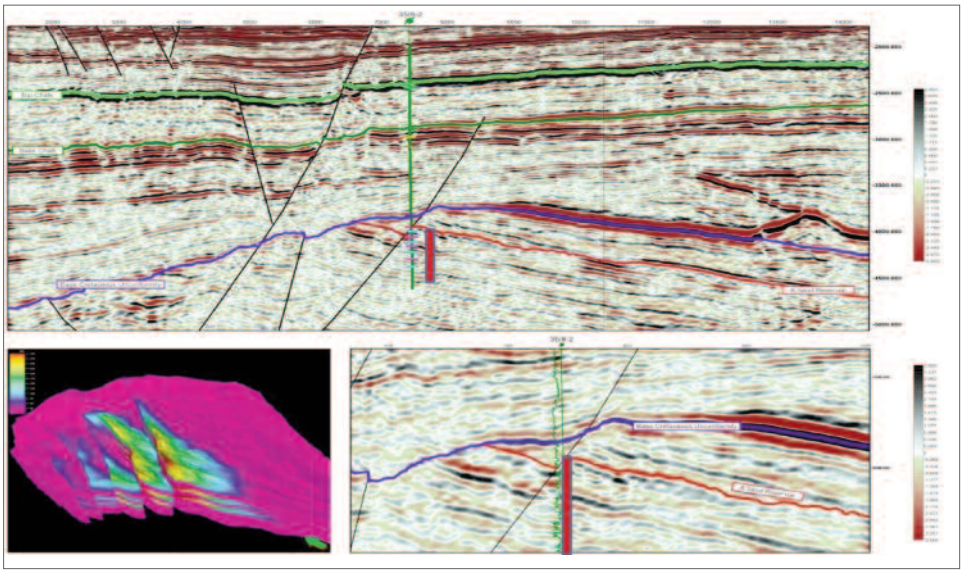


Figure 8 Seismic reflection profile through the 35-8-2 Spanish Point discovery well, northern Porcupine Basin, offshore Ireland (PR).

Figure 9 Carboniferous sandstone and coal outcrops, Murlough Bay, Antrim, Northern Ireland (PR)

The Tellus Border

Abstract only — please see Editorial

Dr Marie Cowan
(Geological Survey of Northern Ireland)

The Tellus Border Project is an EU INTERREG IVA-funded project that has collected airborne geophysics and geochemistry data in six border counties of the Republic of Ireland: Donegal, Sligo, Leitrim, Cava, Monaghan and Louth. This project, let by the Geological survey of Northern Ireland in partnership with the Geological Survey of Ireland, Dundalk Institute of Technology and Queen's University Belfast, follows on from the award-winning Tellus Project, and has produced seamless, merged data sets of the northern 12 counties of the island of Ireland.

New data will provide assistance in geological mapping, as well as research into the environmental, health, agricultural and planning sectors. Geophysical and geochemical data from the Republic of Ireland are free to download from the project website: www.tellusborder.eu. The data are already being used by research teams in NI, RoI and GB.

Preliminary interpretation of the data has enabled regional structures to be mapped, and has identified previously un-mapped or buried features, as well as mapping radon, caesium minor occurrences, elemental deficiencies and toxicities.

From bugs to birds and beyond: reconstructing the colours of fossil insects and feathers

Abstract only, with photographs — please see Editorial

Dr Maria McNamara
(Lecturer, School of Biological, Earth and Environmental Sciences, U C Cork)

Coloration is a key element of the phenotype of modern animals and underpins diverse inter- and intraspecific communication strategies, but its evolution is poorly understood. This [situation] stems, in part, from our limited understanding of how colour alters during fossilisation. Structural and pigmentary colours in fossil insects and feathers have emerged as a major focus of recent research. Such studies have revealed aspects of the fine-scale anatomy and function of colour in insects and theropods, but it is becoming increasingly evident that taphonomic factors impact strongly on the record of colour in these groups. In particular, taphonomic experiments using elevated pressure and temperature yield important insights into the diagenesis of colour in insects and feathers during burial and explain key patterns in the fossil record. Future experimental studies have the potential to elucidate aspects of the fossilisation of original colours in diverse taxa.

[Editor's note: Dr McNamara was unable to write up her presentation as an article for the *OUGSJ*, but sent 11 images from her lecture. Dr McNamara's images have been reproduced here at the best sizes suitable to the resolutions of the files submitted. Interested readers can find a short summary of some of Maria McNamara's research when at the University of Bristol, in Laursen, Lucas 2013 'Faux fossils: scientists artificially age insects in a bid to learn how their colors evolved'. *Scientific American* **308** (6) June, 24.]

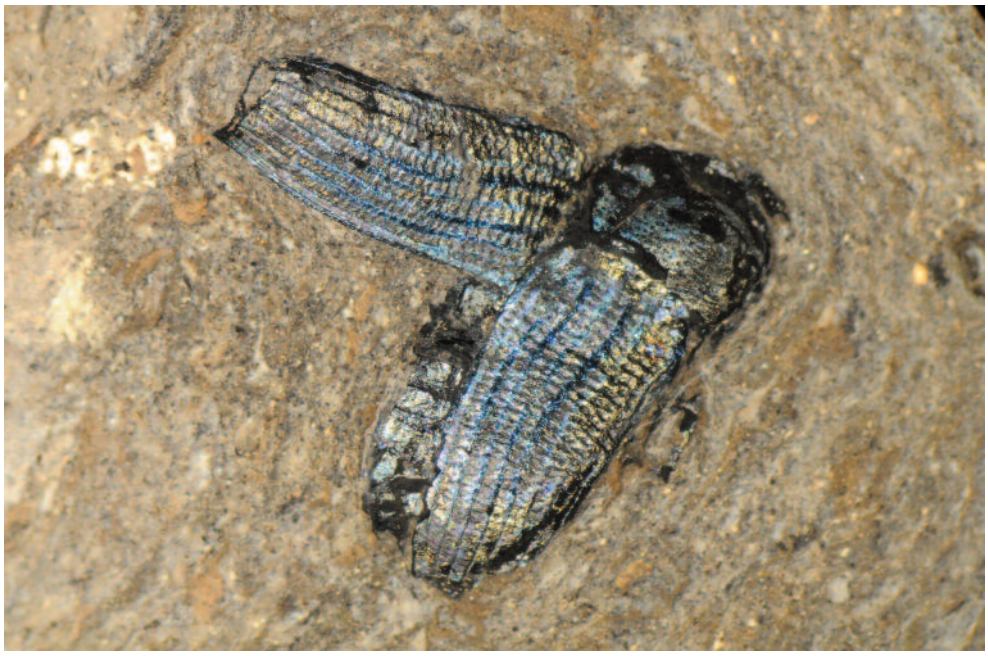


Figure 1 49-million-year-old iridescent beetle from Messel, Germany (© Maria McNamara / Forschungsinstitut Senckenberg).

Figure 2 49-million-year-old iridescent beetle from Messel, Germany (© Maria McNamara / Forschungsinstitut Senckenberg).

Figure 3 49-million-year-old moth with metallic colours from Messel, Germany (© Maria McNamara / Forschungsinstitut Senckenberg).

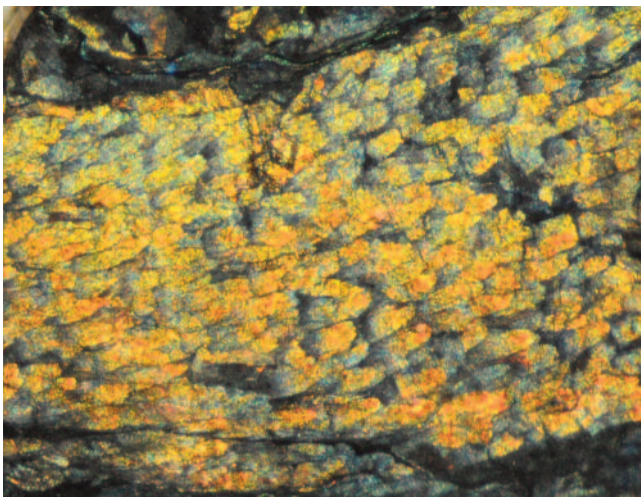


Figure 4 Detail of coloured scales in the fossil moth (© Maria McNamara).

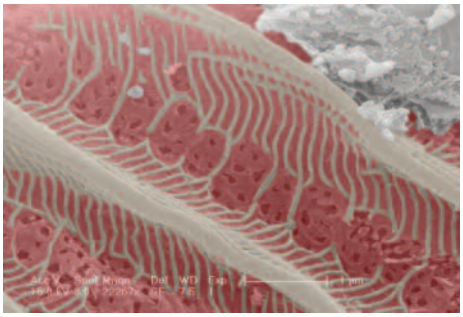


Figure 5 Scanning electron image of complex nanometre-scale structures involved in producing metallic colours in the fossil moth (© Maria McNamara).

Figure 6 125-million-year-old feathered dinosaur Sinosauropteryx from Jehol, China (© University of Bristol).

Figure 7 Scientifically accurate artist's reconstruction of the original colours of Sinosauropteryx based on fossilised melanosomes (© University of Bristol / Jim Robins).

Figure 8 125-million-year-old fossil feather from Jehol, China (© Maria McNamara / University of Bristol).

Figure 9 Scanning electron image of fossilised melanin granules (melanosomes) in a 125-million-year-old fossil feather from Jehol, China (© Maria McNamara / University of Bristol).

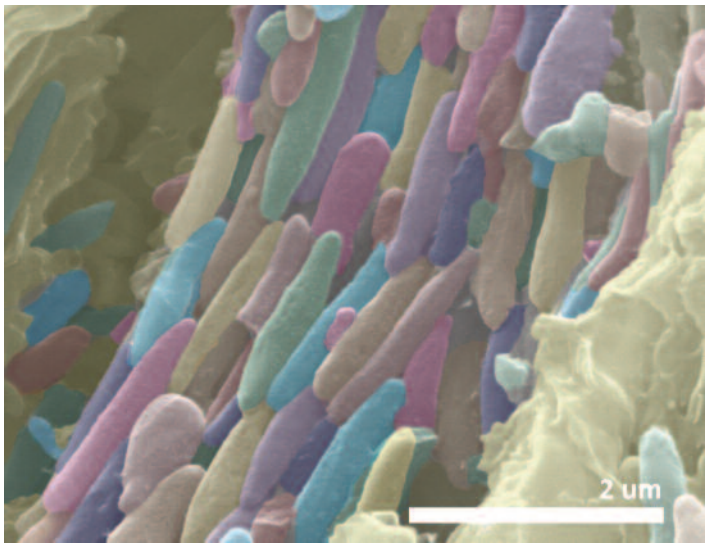
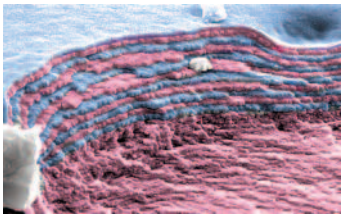


Figure 10 Jewel beetle Chrysochroa rajah *from Thailand (© Maria McNamara).*

Figure 11 Scanning electron image of nanometre-scale layers in the tough outer coating (cuticle) of the jewel beetle Chrysochroa*. These layers scatter light, producing bright structural colours, and are also preserved in the fossil beetles (© Maria McNamara).*



Geological Observations in south-west Pembrokeshire, including Skomer Island and the Marloes Peninsula

John Downes

(jd1936@btinternet.com)

The Marloes Peninsula lies in the south-west corner of Pembrokeshire and it extends westwards towards the islands of Skomer and Grassholm (Fig. 1). These are famous for their large population of breeding seabirds, including the puffin that has been adopted as the logo of the National Park. The seas around Skomer are a designated Marine Nature Reserve providing protection for marine creatures and conserving their environment. The National Trust owns the western half of the peninsula so the area is maintained as much as possible in its natural condition. In spring, when the thrift and sea campion are in bloom on the cliff tops, walking the coast path is a wonderful experience.

While rocks of Lower Silurian age form a broad outcrop extending west-east between Haverfordwest and Narberth on the north side of the Pembrokeshire coalfield, exposures are relatively scarce, so it is much more rewarding to examine the coastal outcrops on the Marloes Peninsula and Skomer, where both the volcanics and sediments can be seen in juxtaposition. The Skomer Volcanic Group can be traced westwards from the Marloes Peninsula through Skomer to Grassholm (Fig. 2) and beyond to The Smalls, a rocky outcrop 28km west of the mainland, on which the Smalls lighthouse is perched. The island of Skomer is similar in structure and geology to the mainland, but it is a National Nature Reserve and SSSI and access is limited.

The Silurian rocks are faulted against the Old Red Sandstone that forms the Dale Peninsula and a broad belt of country that extends along the north side of the Milford Haven. Old Red Sandstone is a collective term for a succession of red mudstones, sandstones and conglomerates that have been folded, faulted and eroded to form the present-day scenery.

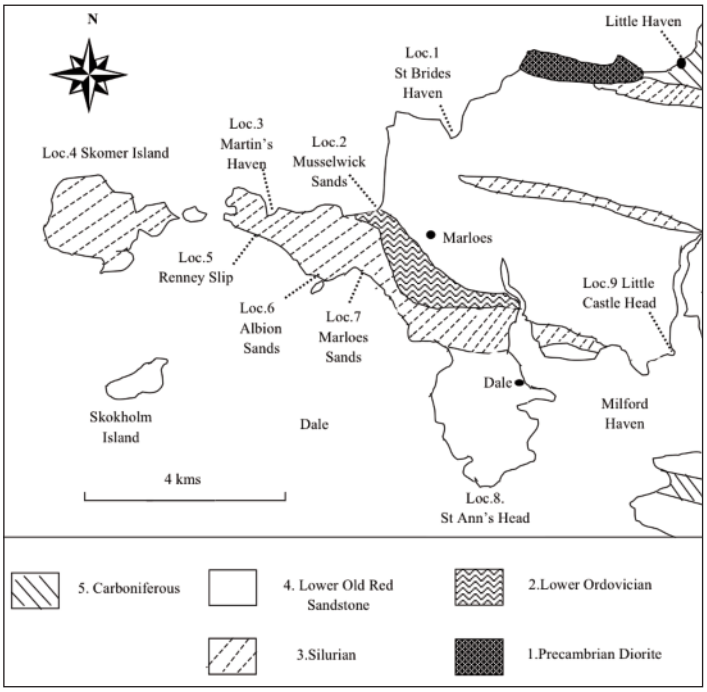
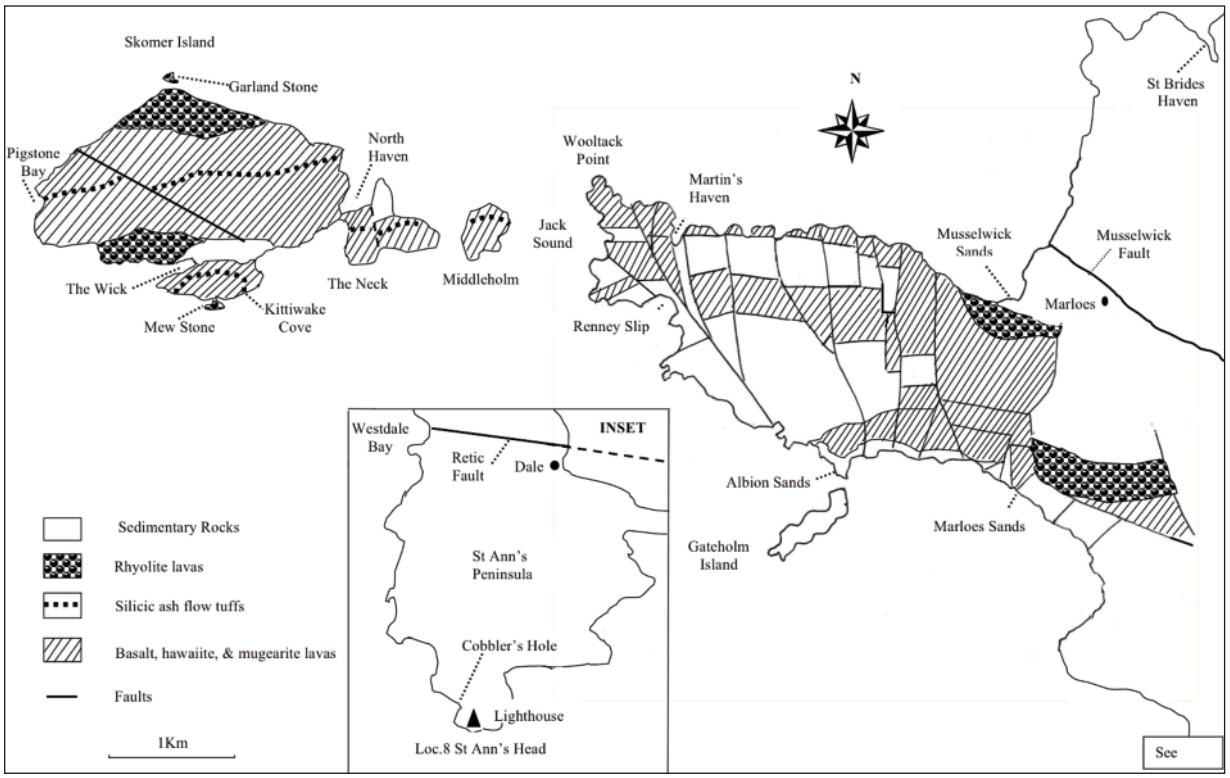


Figure 1 The geology of south-west Pembrokeshire.

Figure 2 Map of the Skomer Volcanic Group on Skomer Island and the Marloes Peninsula.



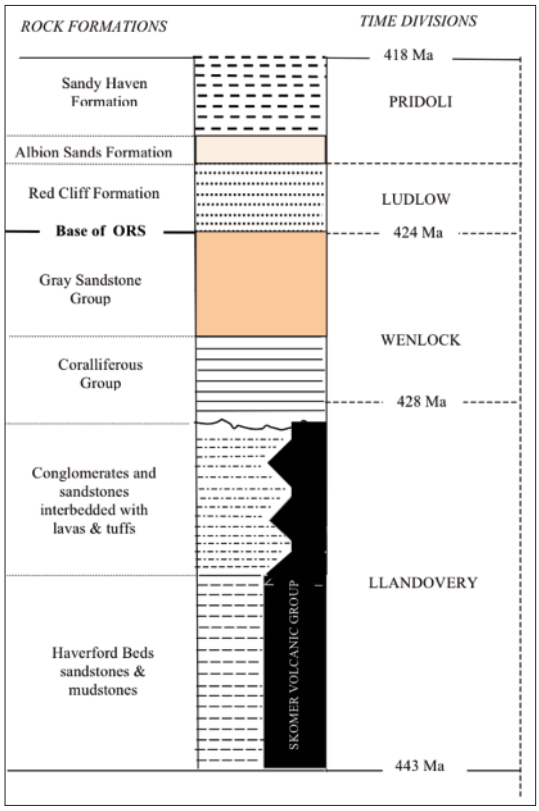
© OUGS ISSN 0143-9472

How and when were these rocks produced? The story begins towards the end of Silurian times when the great upheaval of the Caledonian Orogeny had created a vast mountainous zone that extended across much of Britain. Pembrokeshire lay on the southern margin of these highlands that were subject to intense erosion during the Devonian Period. Torrential streams, heavily loaded with debris, flowed southwards off the mountains and deposited huge amounts of sediment on the coastal lowlands that occupied much of what is now south Pembrokeshire. Meandering braided rivers laid down thick sequences of silt, sand and pebbles that would later form the Old Red Sandstone. In a semi-arid environment, the desiccated sediments often preserved mud cracks and the trails and burrows of organisms that were living on the muddy surface. Also, under conditions of high evaporation, calcium salts were drawn up through the soils to form distinctive deposits known as calcretes, which formed irregular white nodules in many of the red mudstones.

However, the relative quiet conditions of Old Red Sandstone sedimentation were interrupted from time to time by violent volcanic outbursts across south Wales. Each Plinian eruption produced a huge gaseous ash cloud rising up to 20km above the vent and the fall-out would spread over an area of several 1,000km^2. In Pembrokeshire, the occurrence of tuff bands formed of compressed ash in the Lower Old Red Sandstone shows that volcanic activity was relatively frequent and the sedimentary structures within the ash bands suggest that it was often laid down in shallow water. Despite the widespread occurrence of these layers of ash, there is no visible evidence of the presence of the volcanic centres that generated the airfall material.

The Old Red Sandstone is a continental-type deposit and not a geological time period. It was laid down from *c.* 424 Ma in the Upper Silurian (Fig. 3) to the end of Devonian times (354Ma).

Figure 3 Stratigraphical Column for the Silurian Rocks of south Pembrokeshire.



Since 1972, the internationally agreed boundary between the Silurian and Devonian periods has been set (using the base of a graptolite zone in the marine sediments of the Barrandian region of what is now the Czech Republic) at *c.* 418Ma.

Much of the Old Red Sandstone has been affected by the Variscan Orogeny that began in Upper Carboniferous times. The resulting tectonic structures can be seen across south Pembrokeshire, as for example in Cobbler's Hole on St Ann's Head. The Ritec Fault is another example of a Variscan tectonic feature that can be traced from Westdale Bay across the Dale Peninsula and along the Milford Haven waterway towards Pembroke.

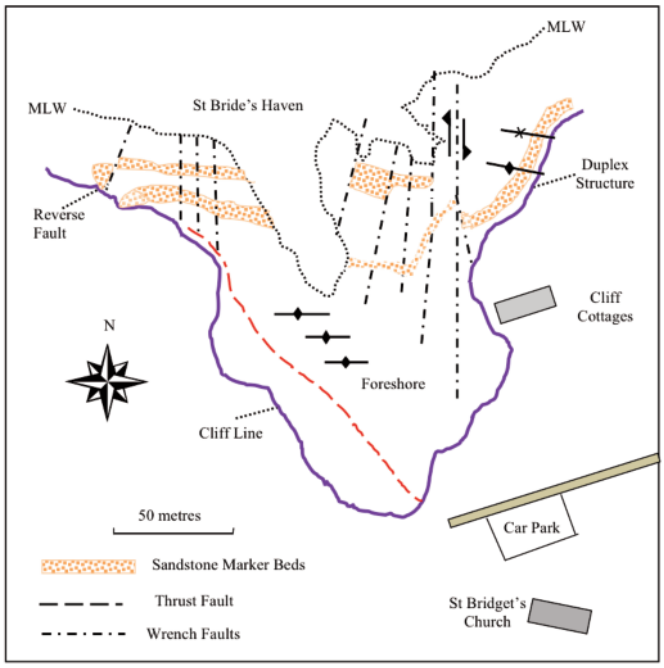
Localities to Visit

1. St Brides Haven [SM 802110]

This is another of my favourite places on the Pembrokeshire coast, being a quiet, unspoilt bay that offers some fascinating structural geology. St Brides lies on the rugged west coast and can be reached by a narrow lane from the crossroads at SN 833104 on the B4327 from Haverfordwest. There is a small car park next to the church overlooking the haven. You should visit this locality at low tide when most of the Variscan structural features are exposed on the foreshore. The mudstones and sandstones of the Sandy Haven Formation dip gently southwards at *c.* 10˚ and they are cut by numerous dextral wrench faults running approximately north-west across the foreshore (Fig. 4). Several smaller splay faults can also be seen. The positions of the main faults are marked by narrow gullies where the sea has eroded along the lines of weakness. The most obvious fault can be seen on the east side of the haven where a sandstone marker bed is offset dextrally by about 20m. Several sandstone beds can be traced across the foreshore, although it is not always easy to identify them owing to encrustation by barnacles.

You will notice Cliff Cottages standing above the east side of the bay. These provide ideal holiday accommodation for geologists wanting to be near to the rocks! About 50m north of the cottages there is a grey conglomerate unit *c.* 2m thick, overlying cleaved red mudstones at the base of the cliff. You will see that the calcretes in the mudstone have been flattened and elongated

Figure 4 Structural geological map of St Bride's Haven.



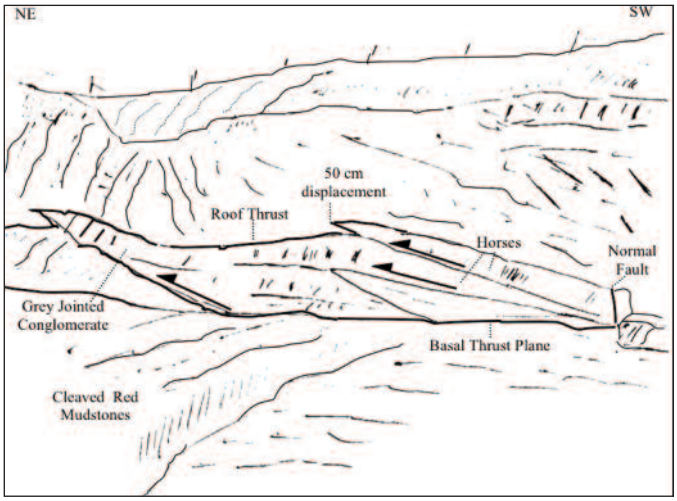


Figure 5 A thrust duplex structure in the Sandy Haven Formation at St Bride's Haven.

Figure 6 A thrust duplex structure at St Brides Haven — east side.

by the development of a near-vertical cleavage. Now carefully examine the conglomerate and notice that it is cut by several sub-parallel thrust faults that separate the conglomerate into separate segments called 'horses' (Fig. 5). The pressure has clearly come from the south, as the hanging walls have been thrust to the north over the underlying footwalls. This displacement is up to 0.5m on each thrust and represents the amount of crustal shortening that has taken place. Look for slickenside striations on some of the thrust planes. There is a basal thrust plane below the conglomerate and a roof thrust above it. Here we have a marvellous example of what is known as a thrust duplex, in which successive segments from the footwall have become incorporated into the hanging wall (Fig. 6).

Finally, walk over to the north-west side of the haven where a prominent reverse fault runs along the base of the cliffs in a NW–SE direction. The sandstone beds above the fault plane form the hanging wall that has been pushed up and over the folded beds in the footwall. The thrust movement is again in a northerly direction.

2. Musselwick Sands [SM 785088]

Musselwick Sands are located on the north coast of the Marloes Peninsula and can be reached from the Marloes to Martin's Haven road by a footpath that begins near Marloes Beacon [SM 786085]. You will find parking space available alongside the road. Follow the footpath across the fields to Black Cliff [SM 785090]. This locality lies near the faulted junction between the Skomer Volcanic Group (to the south-west) and dark grey Ordovician mudstones. The cliff face provides an excellent exposure of the mudstones that represent a turbidite sequence deposited in the deeper waters of the Welsh Basin during the Upper Llanvirn stage. The mudstones contain several thin ash bands *c.* 50mm thick that would have been derived from pyroclastic airfall material. The bands dip at *c.* 30˚ SSE, but the whole sequence is intensely deformed by strong cleavage (Fig. 7) with a NE–SW strike direction, resulting from the Caledonian earth movements. Above the high-tide mark the mudstones weather to a rusty orange colour, which is indicative of the presence of iron sulphide and this mineral commonly forms in muds under anoxic conditions on the sea floor. About 200m north-east of Black Cliff the mudstone outcrop is terminated by the Musselwick Fault that thrusts Ordovician strata northwards over younger Old Red Sandstone rocks. The fault can be traced across country reaching as far east as Sandy Haven Pill on the shores of Milford Haven.

On the south-west side of the bay the mudstones are faulted against rhyolitic lavas of the Skomer Volcanic Group of Group that extend for *c.* 200m along the cliff face to Hopgang [SM 779089]. The exposure in these cliffs appears to be a silicified type of rhyolitic lava that can be examined in the fallen boulders on the beach. The faulted junction between the mudstones and the rhyolites is difficult to see owing to rock falls, but the volcanics appear to have been thrust northwards over the mudstones. Please be aware that there is a danger of being cut off by the incoming tide on this beach, as the only way out, via Black Cliff, becomes impassable after half tide.

3. Martin's Haven [SM 760091]

This tiny inlet lies at the north-western end of the Marloes Peninsula. You should drive along the B4327 from Haverfordwest and take the minor road through Marloes village continuing onto the National Trust car park at Martin's Haven. When you walk down the road to the haven you will see, in the cutting below the car park, some exposures of quartzitic sandstone that occur within the Skomer Volcanic Group. On the eastern side of the shingle beach the low cliffs display several

Figure 7 Ordovician turbidite mudstones at Black Cliff, Musselwick Bay.

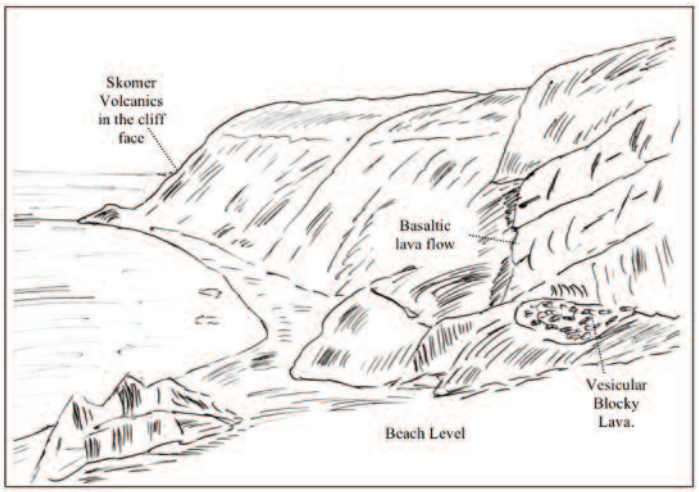


Figure 8 Martin's Haven — east side.

Figure 9 Basaltic blocky lava flow (Skomer Volcanic Group) in Martin's Haven.

basaltic lava flows within the Skomer Volcanic Group (Fig. 8) that have a rough clinkery and blocky appearance (Fig. 9) that is sometimes known by the Hawaiian term áa. Some of these lavas have distinctively reddened top surfaces suggesting that they may have been exposed to subaerial weathering. At the head of the bay there is a bed of pyroclastic flow material sandwiched between the lavas. It contains several blocks of basalt and smaller volcanic fragments or lapilli set in layered coarse ash. Much of the basalt here is vesicular, indicating that the lava was originally highly gaseous. There are patches where the basalt has been altered to the distinctive pistachio-green mineral epidote and later cut by calcite veins.

On the west side of the bay there is a small promontory leading to the landing stage that is used by the boats operating a summer service to the Skomer Island Nature Reserve. This outcrop is formed of rhyolitic conglomerate and tuff that is also present to the west of the N–S fault running down the access road. The conglomerate is composed of pebbles and cobbles of volcanic rocks up to 300mm across. The fragments are angular to well-rounded and the unit is well-bedded implying that this is a deposit of volcanic material that was reworked and deposited in shallow water environment.

Figure 10 Weathered mafic lavas near South Haven, Skomer; Skokholm Island is in the distance.

While visiting Martin's Haven it is worth walking around the Wooltack Peninsula that is also known as the Deer Park. Enter the park by the stone gateway and climb the path to the old coastguard lookout [SM 758092]. From here there are excellent views across to Skomer Island (Skomer Volcanic Group) in the west and to Skokholm Island (Old Red Sandstone) in the south. Wooltack Point and the north coast of the peninsula are composed almost entirely of basaltic/andesitic lava flows but on the south-west coast there are mudstones, sandstones and conglomerates interbedded with lava flows. The latter show well-developed pillow structures on the south side of Jeffry's Haven where a natural arch has been eroded in the basalt. The small bay to the south displays sediments that are folded into a tight-faulted syncline. About 200m farther south is The Anvil, where yet another basaltic flow forms the resistant headland.

4. Skomer Island [SM725095]

During the summer tourist season The *Dale Princess* sails from Martin's Haven to North Haven on Skomer. Details can be obtained on Freephone 0800 0284090. Since Skomer is a National Nature Reserve, visitors are required to keep to the marked paths. The island is famed for its wildlife, including grey seals, puffins, guillemots, razorbills, fulmars, cormorants and shearwaters.

Geologically most of Skomer is formed of rocks belonging to the Skomer Volcanic Group, which is of Lower Silurian age (Llandovery Series). The lavas dip southwards so that the oldest outcrop is in the north. These are thick flow banded rhyolites that occur on the northern tip of the island and they are well exposed on the Garland Stone. Much of the island is formed of lava flows composed of alkali feldspar-bearing basalts (hawaiite and mugearite) that strike approximately E–W. They are cut by a major dextral wrench fault that runs diagonally across the island from Bull Hole in the north-west to South Haven in the south-east (Fig. 10). The displacement on this fault is *c.* 150m and this can be clearly seen in the centre of the island where the E–W line of weathered volcanic crags is offset to the south-east. There is a distinctive 6m thick silicic ash flow tuff (welded pyroclastic flow deposit) that can be traced across Skomer from Pigstone Bay in the west to North Haven in the east. On the south-west coast around The Basin there are rhyolite lavas that show well developed flow banding and flow folds. The lavas are also nodular in places with

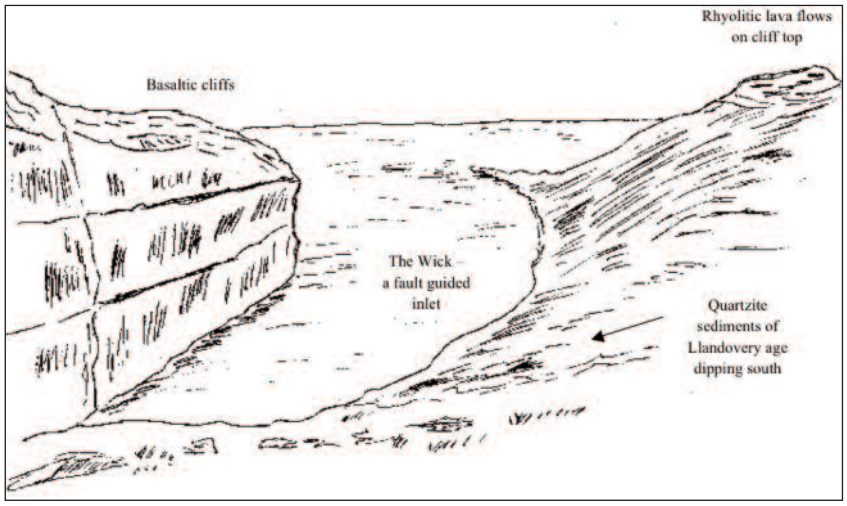


Figure 11 View looking south-west at The Wick, Skomer Island.

Figure 12 The Wick: a fault-guided inlet on the south-west coast of Skomer Island.

layers of spherulites, some of which are up to 250mm in diameter. On the south coast of Skomer is the spectacular chasm known as The Wick (Figs 11 and 12) that is developed along a fault line where a narrow outcrop of sedimentary quartzite has been deeply eroded. South of The Wick the lavas contain a distinctive red silicic tuff known as the Skomer ignimbrite, which is exposed in Kittiwake Cove. This is an important stratigraphical horizon, as it can be traced through Midland Island to Jeffry's Haven on the Marloes Peninsula. The youngest rocks in the Skomer succession are represented by the rhyolites on the Mew Stone.

5. Renney Slip [SM 760088]

This small bay lies on the south side of the narrow neck of land that separates it from Martin's Haven. From the National Trust car park follow the track to the southern end of the Deer Park wall that overlooks Renney Slip. Here there is a steep narrow, winding path down the cliffs to the beach and you must take great care in negotiating this path. In the interests of safety it is recommended that you do not attempt the descent alone. The highest basalt flow in the Skomer Volcanic Group is *c.* 7m thick and has been traced from Limpet Rocks 200m offshore through the headland dividing Anvil Bay and Renney Slip (Fig. 13). It is repeated by faulting and so can be seen outcropping near to the bottom of the path at beach level in Renney Slip. The basalt is vesicular and has a cindery upper surface. The mudstone immediately above the basalt contains pebbles of igneous material. The succeeding conglomerates and sandstones that outcrop in the north side of Renney Slip display ripple marks and cross-stratification on the bedding planes that dip steeply to the south-east. The overlying micaceous mudstones, which can be seen in the sea stacks in the centre of the bay, contain a diverse brachiopod fauna. The brachiopods include *Eocoelia hemisphaerica*, which is an important zone fossil of the Upper Llandovery. Casts of *Eocoelia* can be seen in some of the blocks on the foreshore.

In the steep-sided promontory along the southern side of Renney Slip, there are siltstones overlaid unconformably by the sandstones that belong to the lower part of the Coralliferous Group (Fig. 14). The latter contrast markedly with the succeeding grey mudstones that outcrop at the top of the rock wall and dip south-east into Deadman's Bay. Unfortunately it is difficult to access Deadman's Bay even at low tide, but there are many large fallen blocks of the grey mudstone at the foot of the rock wall containing the casts of brachiopods such as *Costistricklandia lirata*. The latter is restricted to the Upper Llandovery and so gives an indication of the age of the base of the Coralliferous Group in this area.

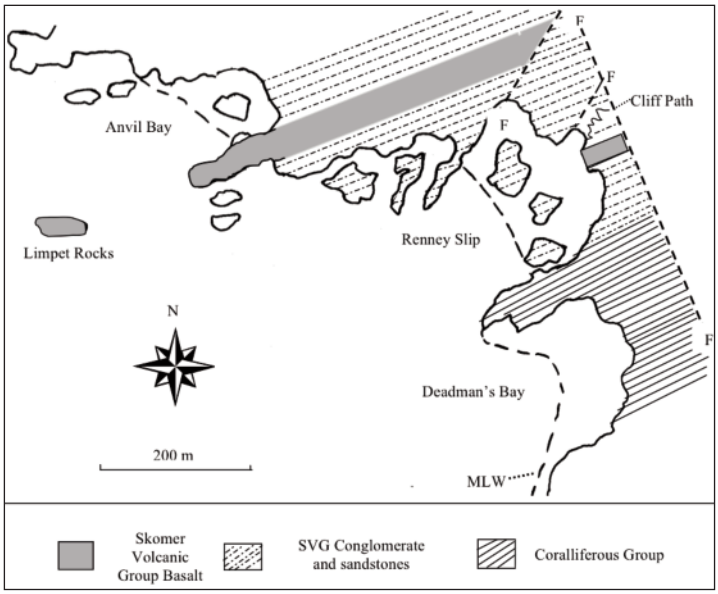
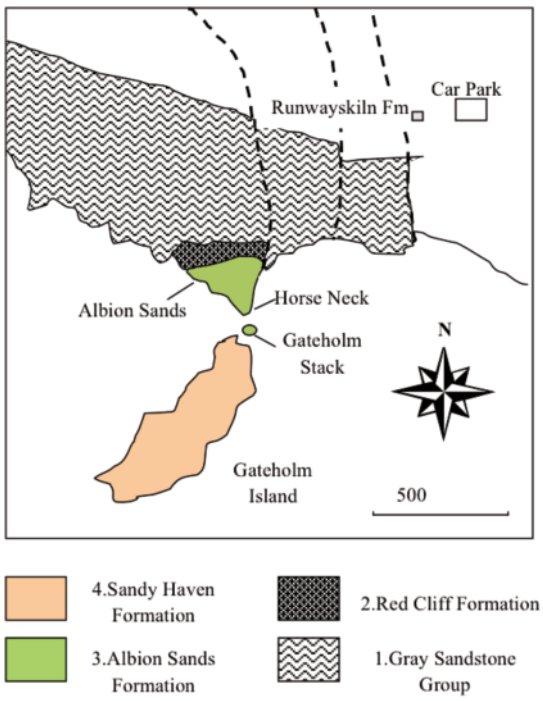


Figure 13 Geological map of Renney Slip and Deadman's Bay.

Figure 14 Renney Slip (foreground) separated from Deadman's Bay by a promontory of sandstones and mudstones of the Coralliferous Group.



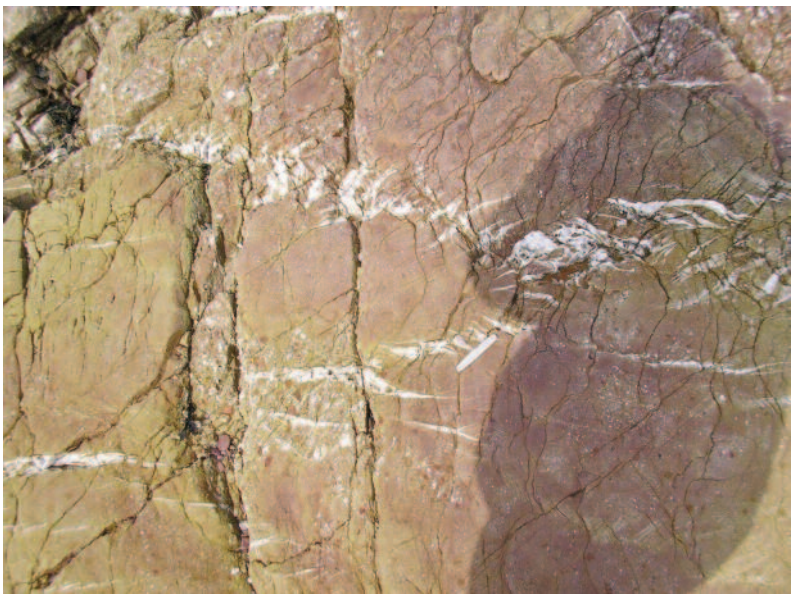


Figure 15 The geology of Albion Sands and Gateholm.
Figure16 Conjugate shear zones with en échelon *quartz-filled tension gashes in the Albian Sands Formation.*

6. Albion Sands [SM 772076]

You can reach this locality from the B4327 Haverfordwest to Dale road by turning right at Mullock Bridge [SM 810082] along the lane to Marloes. Before entering the village turn left along the single-track road leading to the National Trust car park [SM 780081] near Runwayskiln Farm. Walk along the bridle track that runs south-west from the car park entrance; it is signposted to a youth hostel. Continue along the track past the Nature Reserve at Marloes Mere and then bear left along the footpath leading to the coast. You get an excellent view of Gateholm Island from the cliff top, from where you can look down to Albion Sands on the west side of the Gateholm promontory. The sands are named after the paddle steamer *Albion* that was beached here in April 1837 after striking a rock as it was negotiating Jack Sound, the dangerous tidal race between the Marloes Peninsula and Skomer Island. The *Albion* was a two-masted, schooner-rigged, wooden vessel of 270 tons with her engines powered by coal-fired boilers. Unfortunately once the hull was holed, the engine room soon flooded and the crew were lucky to reach the relative safety of Albion Sands before the ship broke up. At low tide you can still see part of a cast iron beam standing out of the water. This is all that remains of the 170-year-old wreck.

There is a steep rugged path leading down to the foreshore at SM 772077 where the cliffs project towards Gateholm Island. This path can be slippery in wet weather so you should take great care on the descent. When tide is low you can walk around Gateholm stack and climb up onto the island if you wish, although the best rock exposures are in the cliffs around Albion Sands. However, Gateholm is a good example of what geographers call a tombola, which is an island separated from the mainland only at high tide.

The Red Cliff Formation at the base of the Old Red Sandstone succession in Pembrokeshire (north of the Ritec Fault) is exposed at the northern end of Albion Sands beach (Fig. 15). These rocks rest directly on the Gray Sandstone Group of the Silurian inlier that forms the Marloes Peninsula. The Red Cliff Formation consists of red mudstones and interbedded calcretes with cross-stratified fine sandstones, representative of an estuarine environment, which from time to time dried out to produce mud cracks and calcrete deposits.

A metre-thick cleaved purple/red airfall tuff outcrops on the foreshore at SM 772077 and this marks the junction with the succeeding Albion Sands Formation that contains red mudstones, yellow/buff coloured sandstones and conglomerate beds, which can best be examined at the base of the cliffs around Horse Neck [SM 772075] on the north side of the gap between the mainland and Gateholm Island. The cross-stratified multi-storey sandstone beds often rest on erosion surfaces and sometimes contain lenses of conglomerate in which there are large mudstone clasts. Some of the conglomerates contain sandstone clasts 400–500mm across; such beds are characteristic of braided rivers, which, when in spate, bring down large amounts of debris. Several darker-coloured igneous pebble conglomerates can be identified in the vicinity of Gateholm Stack, providing further evidence of volcanic activity in the area. These pebble beds are thought to belong to the Lindsway Bay Formation, which interdigitates with the Albian Sands beds and is a coeval formation fully developed on the north shore of the Milford Haven.

The most spectacular tectonic structures within the Albion Sands Formation are the sets of *en échelon* tension gashes that occur on the sandstone bedding planes around Horse Neck. These gashes or fractures are filled with quartz and lie parallel to each other at an angle of *c*. 45˚ to the direction of the set. The staggered or *en échelon* arrangement of the mineral veins defines a shear zone within the rock in which the tension gashes were opened up as the rock mass moved in opposite directions in response to the compression created by the Variscan earth movements. You should be able to find examples where two sets of gash veins intersect on the rock face (Fig. 16). These are referred to as conjugate sets of shear zones.

7. Marloes Sands [SM 781077]

This is a popular beach for holidaymakers in the summer months, and at low tide there is a large area of sand and rocks exposed for people to explore. You can get to this locality from Marloes village by following the narrow road that is signposted at the

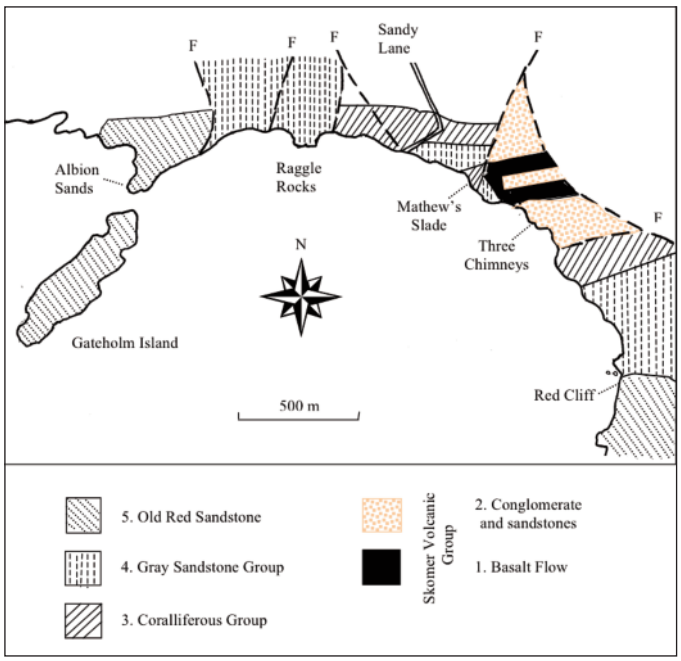


Figure17 View looking south-west across Raggle Rocks to Gateholm Island (far left).

Figure 18 Geological map of the coastal area between Gateholm Island and Marloes Sands.

turning near the church. There is a National Trust car park at the end of the road [SM 780082] near Runwayskiln Farm. You will need to bring your own refreshments as there are no facilities on the beach. Walk back up the road and turn right onto Sandy Lane that leads down to the coast. Before you get onto the beach do take the opportunity of looking westwards towards Gateholm Island. This is a view beloved of local artists, showing the upstanding jagged rocks on the foreshore with the eroded plateau surface of Gateholm in the background (Fig. 17).

When you reach the beach, turn left and walk *c.* 250m to a large grass-covered hollow in the cliffs known as Mathew's Slade (Fig. 18). This is a good point to start examining the succession of Silurian strata that extends upwards into the Old Red Sandstone at Red Cliff *c.* 1km to the east. The mudstones at Mathew's Slade [SM 784075] are a faulted slice of the Coralliferous Group where the brachiopod fauna includes *Costistricklandia*, *Eocoelia* and *Atrypa*. These fossilliferous beds are faulted on the east against a sequence of feldspathic sandstones belonging to the upper part of the Skomer Volcanic Group. The sandstones are succeeded by two basaltic lava flows that are exposed in a deep gully *c.* 100m to the east of Mathew's Slade [SM 785074]. The lavas have a total thickness of *c*. 25m, and they are vesicular, being full of gas bubbles when originally extruded. The brecciated and weathered scoriaceous tops of the flows suggest that they were produced by subaerial volcanic activity.

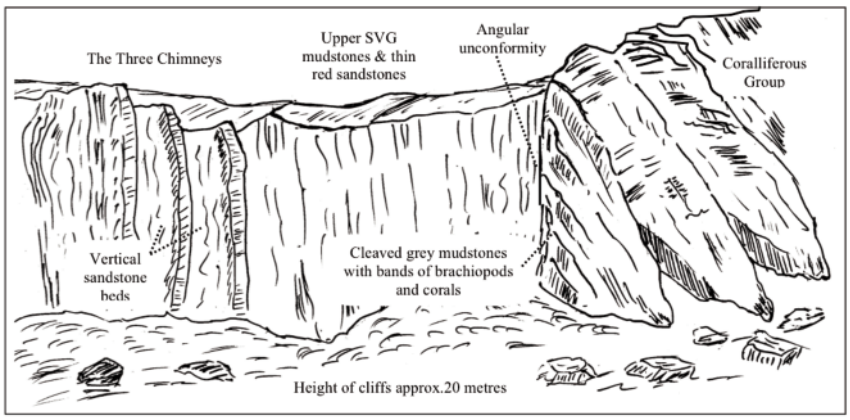
The lavas are succeeded by a sequence of *c*. 90m of conglomerates and sandstones interbedded with tuffaceous mudstone bands containing the brachiopod *Lingula*. Cross-stratification, ripple marks and scour structures in the sandstones provide evidence of a shallow water coastal environment. Airfall deposits from nearby volcanoes would have produced volcaniclastic sediments as the volcanic ash was deposited in the shallow seas.

Approximately 200m to the east of the basalt flows you will see a cliff feature known as The Three Chimneys (Fig. 19). This rock face is formed of near vertical sandstone pillars that stand out in the cliff from the less resistant interbedded sandy mudstones. The succeeding flagstones at the top of the Skomer Volcanic Group contain brachiopods such as *Lingula* and *Leptaena*.

About 100m to the east of the Three Chimneys the beds are faulted and overlaid unconformably by the Coralliferous Group. There is an angular discordance of *c.* 10˚ between the two units that is best seen by standing several metres back from the cliffs. The lower beds of the Coralliferous Group consist of sandstones, cleaved mudstones and shelly calcareous lenses. The latter are exposed in the fallen blocks and cliff recesses around SM 787072 that yield the brachiopod *Eocoelia sulcata* and the coral *Palaeocyclus porpita* both of which determine the Upper Llandovery age of the rocks. A few metres higher in the succession the brachiopod *Costistricklandi lirata* becomes abundant along with the tabulate colonial coral *Favosites*.

In the 1960s Alfred M. Ziegler demonstrated that brachiopod communities can be used as water depth indicators. *Lingula* communities generally occupy shallow littoral environments; *Eocoelia* communities are found in water *c*. 20m deep and *Costistricklandia* communities inhabit depths of up to 50m offshore. Thus the changes in brachiopod species within the strata outcropping between the Three Chimneys and about the first 20m of the Coralliferous Group suggest marine transgression with

Figure 19 Vertical strata of the Skomer Volcanic Group near Three Chimneys, Marloes Sands.


The Three Chimneys
Upper SVG mudstones & thin red sandstones
Angular unconformity
Coralliferous Group
Vertical sandstone beds
Cleaved grey mudstones with bands of brachiopods and corals
Height of cliffs approx.20 metres

deepening water conditions. However, farther to the south-east towards the middle of the Coralliferous section, *Costistricklandia* disappears, indicating a return to shallow water conditions. Ziegler also argued that lava flows influenced the development of fossil communities. The lavas at Marloes Sands and Renney Slip flowed out onto sediments containing an *Eocoelia* community causing a shallowing of the sea. The *Eocoelia* were buried beneath the lavas and a *Lingula* community slowly became established in the shallow littoral zone above the flow, where sandy and tuffaceous sediments were being deposited.

The junction between the cleaved mudstones of the Coralliferous Group and the overlying Gray Sandstone Group is obscured by fallen blocks, but the flaggy sandstones and mudstones that extend some 350m to the south-east are rather barren of fossils. However, the gradual increase in grain size up the sequence indicates stronger current activity and increased sand supply. This suggests that the environment was changing from shallow marine to low-lying deltaic conditions.

The highest beds of the Gray Sandstone Group are exposed in the sea stacks just west of Red Cliff. Here they are interbedded with thin red-coloured sandstones that herald the approach of Old Red Sandstone sedimentation. At Red Cliff [SM789067] the base of the Old Red Sandstone is indicated by a bench-mark cut into the rock in 1916 by officers of the Geological Survey. However, at that time it was considered that the major environmental change from marine Silurian to terrestrial Old Red Sandstone took place at the start of the Devonian period, but more recent research has shown that the change occurred much earlier, in the Upper Silurian, *c.* 424 million years ago.

8. St Ann's Head [SM 806028]

Drive along the B4327 road from Haverfordwest to Dale village and then follow the narrow lane to the National Trust car park [SM 803042] that is *c*. 1km north of the headland. You should then walk past the cottages at Kete, then turn right and take the footpath across the fields to the Frenchman's Bay. Here the Lower Old Red Sandstone (Freshwater West Formation) dips steeply north since the strata lies on the southern flank of the Pembroke Syncline. Follow the cliff path around the bay to the south side where the beds dip directly into the sea. During winter storms when these bedding planes are well lubricated, this area is subject to rock slides as huge boulders crash down onto the foreshore. Continue to small cove with the delightful name of The Vomit where the path joins the road to St Ann's Head. Walk past the coastguard station to the steep-sided inlet called Cobbler's Hole. The warning sign says 'Do not proceed beyond this board', which is good advice, considering that there is a sheer drop to the sea some 30m below. If possible, I suggest that you visit this locality in the morning when the sun is in the south-east, so that it illuminates the magnificent Variscan fold structures displayed on the north-west face of the inlet (Figs 20 and 21). Compression on the inner fold arcs and extension on the outer arcs has resulted in flexural slip between the beds. This is similar to what occurs when a telephone directory is bent and the pages slide over each other. You should observe the prominent thrust fault that cuts across the nose of the syncline and offsets the fold axis. The beds below the fault have moved to the right in the opposite direction to those above. The sequence of mudstones and sandstone layers shows cleavage developed parallel to the axial plane of the folds. The eastern limb of the anticline is cut by a steep normal fault, which downthrows the strata to the north-east by *c*. 3m.

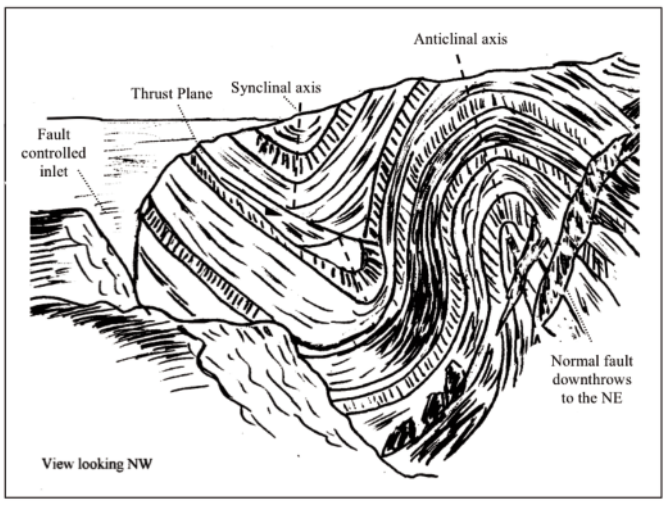
9. Little Castle Head [SM 855065]

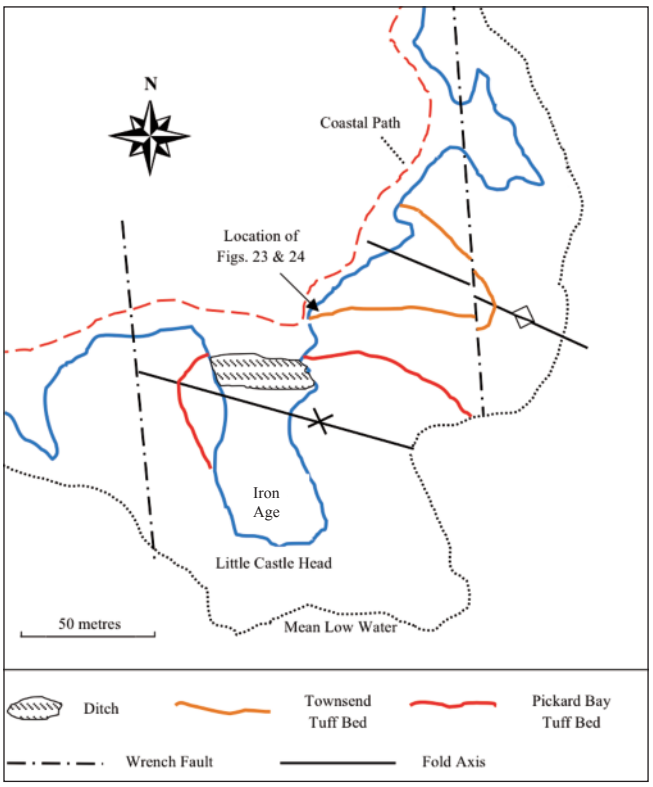
This headland stands at the entrance to Sandy Haven on the north side of the Milford Haven. You can get to this locality by taking the minor road from Milford Haven through Herbrandston, around the head of Sandy Haven Pill and then turning left down a narrow road signposted to the hamlet of Sandy Haven where stepping stones cross the mouth of the pill (a local name for a small tidal inlet). Unfortunately there is no car park here, but there are several places where it is possible to leave vehicles alongside the road.

Take the coast path southwards along the western side of Sandy Haven for *c.* 1.5km to Little Castle Head. Walk across the ditch and earthworks that protect the Iron Age fort and make your way over to the east side of the headland, where there is a good overview of the small bay below the cliffs (Fig. 21). Here the red mudstones of the Sandy Haven Formation are exposed on the foreshore and a distinctive greenish-coloured airfall tuff band known as the Townsend Tuff Bed can clearly be traced as a V-shaped outcrop pointing seawards. This band emphasises the outline of an anticlinal fold plunging to the south-east.

Figure 20 Sketch of Variscan folding in Lower Old Red Sandstone at Cobbler's Hole near St Ann's Head.

Figure 21 Variscan folding in the Lower Old Red Sandstone at Cobble's Hole, St Ann's Head (photo by Chris Downer).





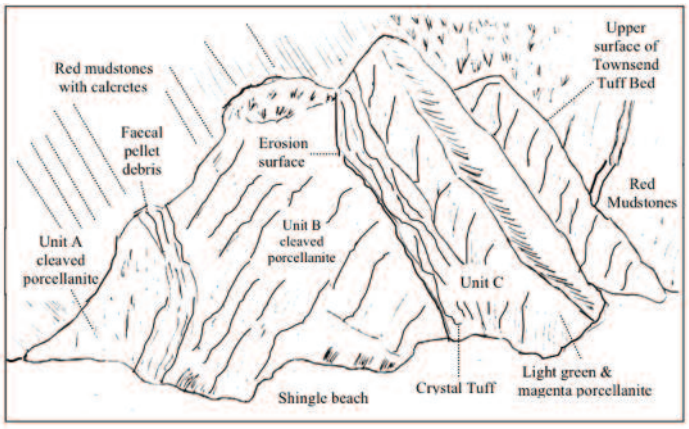


Figure 22 Geology of the foreshore at Little Castle Head.
Figure 23 The Townsend Tuff Bed at Little Castle Head.
Figure 24 (below) The Townsend Tuff Bed exposed at beach level at Little Castle Head.

Immediately below the cliff you should be able to see a complementary syncline in which the Pickard Bay Tuff Bed occurs. This tuff band is younger than the Townsend Tuff Bed since it lies *c*. 20m higher in the Sandy Haven succession.

Take great care when you scramble down the rock slope leading to the foreshore in the south-east corner of the headland and carefully work your way round into the small bay that you have observed from above. This can only be achieved safely at low tide. It is well worth the effort to get to the shingle beach below the cliffs, for here you will be able to have 'hands-on' contact with the best exposure of the Townsend Tuff Bed in the whole of Pembrokeshire! The tuff is *c*. 4m thick and it is made up of three fining up airfall units that were produced by Plinian type volcanic eruptions, each of which created a huge ash cloud that was dispersed by the wind and was eventually deposited in the surrounding shallow seas as a volcaniclastic sediment. Each unit begins with a relatively coarse crystal tuff and is overlaid by a fine-grained, light-coloured tuff known as porcellanite. The Townsend Tuff Bed is named after the small settlement of Townsend near Dale where the bed cuts across the foreshore. However, the tuff outcrops consistently near the base of the Lower Old Red Sandstone in Wales and the Welsh Borders and so provides an important marker bed.

This tuff outcrop is remarkable in that it clearly shows all three separate airfall components (Figs 22 and 23). You will notice that all the beds are dipping at *c*. 50˚ NE, although the cleavage is at a high angle to the bedding. The basal airfall unit is strongly cleaved and can be seen on the west side of the outcrop, alongside the gully separating it from the underlying red mudstones. It is separated from the second airfall unit by a thin horizon of uncleaved ash that is formed mainly of faecal pellet debris. This suggests that there was a period of quiescence between eruptions in which organisms colonised the muddy surface that covered the first airfall deposit. The overlying airfall bed is formed of highly cleaved porcellanite at the top of which is a distinctive wavy erosion surface, again marking an interval between eruptive outbursts. The third airfall unit begins with a coarse crystal tuff that passes upwards into another fine-grained porcellanite that has both light green and magenta coloured bands. Finally, on the eastern side of the outcrop, a gully separates the tuff bed from the overlying calcretised red mudstones (Fig. 24).

Sources cited and consulted

Aldridge, R. J., Siveter, D. J., Lane, P. D., Palmer, D., and Woodcock, N. H. (eds) 2000 *British Silurian Stratigraphy*, Peterborough: Geol Conserv Rev Ser No. 19, 96–101, 227–34, 447–51

Allen, J. R. L., and Williams, B. P. J. 1981 'Sedimentology and stratigraphy of the Townsend Tuff Bed (Lower Old Red Sandstone) in South Wales and the Welsh Borders'. *J Geol Soc London* **138**, 15–29

Allen, J. R. L., Thomas, R. G., and Williams, B. P. J. 1982 'The Old Red Sandstone north of Milford Haven', *in* Bassett, M. G. (ed) *Geological Excursions in Dyfed, South West Wales*. Cardiff, 123–49

Barclay, W. J. 2005 'The Anglo Welsh Basin'. *in* Barclay, W. J., Browne, M. A. E., McMillan, A. A., Pickett, A. E., Stone, P., and Wilby, P. R. *The Old Red Sandstone of Great Britain*. Peterborough: Geol Conserv Rev Ser No. 31

Bassett, M. G. 1982 'Silurian Rocks of the Marloes and Pembroke Peninsulas', *in* Bassett, M. G. (ed) *Geological Excursions in Dyfed, South West Wales*. Cardiff, 103–22

Bevins, R. E. 1999 'Wales and Adjacent Areas', *in* Stephenson, D., Bevins, R. E., Millward, D., Highton, A. J., Parsons, I., Stone, P., and

Wadsworth, W. J. *Caledonian Igneous Rocks in Britain*. Peterborough: Geol Conserv Rev Ser No. 17

Cantrill, T. C., Dixon, E. E. L., Thomas, H. H., and Jones, O. T. 1916 *The Geology of the South Wales Coalfield. Part XII. The Country around Milford*. London: Memoir of the Geological Society of Great Britain, 51–81

Cherns, L., Cocks, L. R. M., Davies, J. R., Hillier, R. D., Waters, R. A., and Williams, M. 2006 'Silurian: the influence of extensional tectonics and sea-level changes on sedimentation in the Welsh Basin and on the Midland Platform', *in* Brenchley, P. J., and Rawson, P. F. (eds) *The Geology of England and Wale*s. London, 75–102

Dineley, D. L. 1992 'Devonian', *in* Duff, P. McL. D., and Smith, A. J. (eds) *Geology of England and Wale*s. London, 179–205

Downes, J. 2008 'Field observations in the Old Red Sandstone of the South Pembrokeshire coastline'. *OUGSJ* **29** (1), 10–15

Downes, J. 2008 *Martin's Haven, Report No. 530, Silurian Igneous Geology*. South West Wales RIGS group

Hancock, P. L., Dunne, W. M., and Tringham, M. E. 1982 'Variscan structures in SW Dyfed', *in* Bassett, M. G. (ed) *Geological Excursions in Dyfed, South West Wales*. Cardiff, 221–39

Hillier, R. D. 2002 'Depositional environment and sequence architecture of the Silurian Coralliferous Group, Southern Pembrokeshire, UK'. *Geol J* **37**, 247–68

Hillier, R. D., and Williams, B. P. J. 2004 'Sedimentation and tectonics: the marine Silurian-basal Lower Old Red Sandstone transition in South West Wales'. *Geol J* **39**, 237–56

Hillier, R. D., and Williams, B. P. J. 2006 'The alluvial Old Red Sandstone: fluvial basins', *in* Brenchley, P. J., and Rawson, P. F. (eds) *The Geology of England and Wales*. London, 155–71

Talbot, J., and Cosgrove, J. 2011 *The Roadside Geology of Wales*. London: The Geologists Association, 183–8

Thorpe, R. S., Leat, P. T., Bevins, R. E., and Hughes, D. J. 1989 'Late orogenic alkaline/subalkaline Silurian volcanism of the Skomer Volcanic Group in the Caledonides of South Wales'. *J Geol Soc London* **146**, 125–32

Ziegler, A. M. 1965 'Silurian marine communities and their environmental significance'. *Nature* **207**, 270–72

Survey Maps

Ordnance Survey 1:50,000 Sheet 158 St David's & Haverfordwest
Ordnance Survey 1:25,000 Sheet 36 South Pembrokeshire
Geological Survey 1:50,000 Sheet 226/227 Milford

John Downes is the author of *Folds, Faults and Fossils: Exploring Geology in Pembrokeshire* (2011; Llygad Gwalch, Pwllheli).

Book review

Smith, Alan 2014 *The Landscapes of Cumbria no. 6: The Smaller Lakes and Tarns of Lakeland*. Keswick: Rigg Side Publications (ISBN: 978-0-95446-795-1; 120pp; £8.99)

When I first started studying geology, I heard it said that after a few months I would never look at a landscape in quite the same way again. I find it fascinating to look at landscapes and try to imagine how they might have been formed, even before starting to look at the rocks themselves.

The natural curiosity of the geologist perhaps finds its ultimate expression in the sixth book in the Landscapes of Cumbria series by Alan Smith. Not content with chronicling the 17 large bodies of Lakeland water in his last book, this time Alan examines the estimated 2,000 'Smaller Lakes and Tarns' to be found there. The level of detail is astonishing: Alan claims to have 'found and recognised all the significant sheets of water in the landscape' — almost 150 of them have been photographed and accompany the text.

Yet this is clearly no spotters' guide. The lakes and tarns have been divided into ten chapters based on what ground they are found on, their method of formation or their position in the landscape. Each chapter is introduced with a description and explanation of the processes that formed that particular type of waterbody, then continues with examples of the type accompanied by well-captioned photographs. For its size, there is a huge amount of information contained in the book, with the level of detail pitched just about right for the average armchair enthusiast. Perhaps my only criticism would be that some of the smaller photographs don't show enough detail to add to the text, but even this has the effect of making the book seem even more comprehensive. There is even a glossary and an appendix listing all the OS grid references of all the lakes included in the book.

This book will undoubtedly appeal to more of a niche market than the previous book, which tackled the bigger, better-known lakes, but don't overlook it. A book of this size would barely be noticed in the average rucksack and I think it would be a fascinating accompaniment to a walk in the Lakes. If you're like me, any tool that helps to pick apart the landscape is more than welcome.

— Richard Blagden DipHE (Natural Sciences)

Northumbrian geologists: our geological forebears

Karl Egeland-Eriksen*

BSc (hons) (Open), MRes (Lancs)

While researching the local geology for Northumbria Branch field trips I have found that much of my reference material is based on the work carried out by 'geologists' from the very beginnings of the science as we know it. The same names keep appearing relating to papers and publications from the early 19th century onwards. Much of their work has proven to be not only of local importance, but of national and international level also. Reading the life stories behind these men spurred me on to produce a short series of articles for the *NOUGS Newsletter* on notable local geologists, either born in the region or who have lived and worked in the area and contributed to our knowledge of what lies beneath our feet. The series was intended to run in roughly chronological order, starting with, in my opinion, the father of Northumbrian geology, Mr George Tate. I then discovered further individuals worthy of mention who preceded Tate so had to backtrack.

[Karl wrote five articles in his series for the NOUGS NL*, beginning with the late 18th-century figure, Nathaniel Winch, and finishing with Kingsley Dunham and Thomas Westoll. I found them most interesting and invited Karl to submit the articles to be combined as a single article for all OUGS Members to enjoy. — Ed.]*

Nathaniel John Winch (1768–1838)

Born in Hampton, Middlesex, Winch moved to north-east England while in his teens. He was an iron merchant and anchor smith by trade (Fig. 1). At what point he became interested in natural history I do not know, but his expertise as a botanist, lichenologist and geologist was recognised by him becoming a Fellow of the Linnean Society in 1803 and an Associate in 1821. His main interest was the flowering plants of Northumberland, Cumberland and Durham, but he also studied cryptograms, including mosses. He accumulated a herbarium of more than 12,000 species. He was also active in local society and in 1805 he became Sheriff of Newcastle.

The first significant publication by Winch was the two-volume *Botanist's Guide through the Counties of Northumberland and Durham*, written in conjunction with John Thornhill and Richard Waugh in 1805–7. In 1808 he became an honorary member of the Geological Society of London and, in the same year, became bankrupt! No doubt due to devoting too much time to natural history and not enough to business.

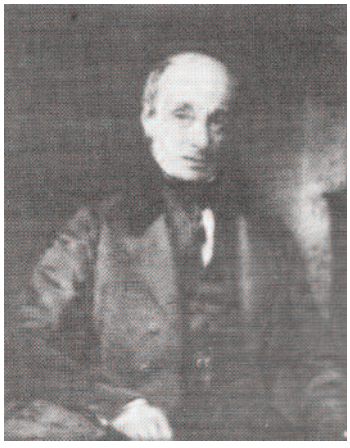


Figure 1 Nathaniel John Winch (author scan).

In 1814 his major geological work, 'Observations on the Geology of Northumber-land and Durham', appeared in the fourth volume of the *Transactions of the Geological Society*. This included sections on the 'Red Marls' of Teesside, the Magnesian Limestone, the Coal Measures, the 'Lead Mines Measures', the beds on the banks of the Tweed and the Cheviot porphyry. It was significant because it was the first occasion that the detailed information on strata obtained by professional miners and quarrymen, along with the extensive coastal exposures, had been gathered together to give an outline of the district's formations (Fig. 2).

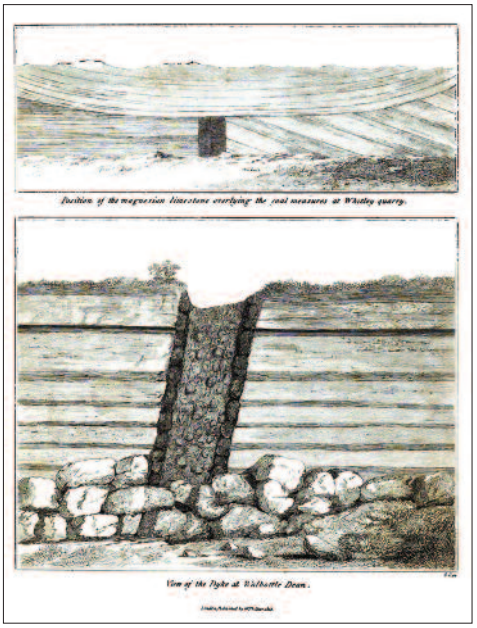


Figure 2 Sketches by Winch from Transactions of the Geological Society *Vol. 4 (Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

In 1829, Winch was elected co-secretary of the Natural History Society of Northumberland and Durham on its foundation. He also served as secretary to the Newcastle Infirmary for 21 years. He died aged 69, unmarried, at his home in Ridley Place, Newcastle upon Tyne in 1838. His manuscripts, library and herbarium were left to the Linnean Society but the greater part was subsequently passed on to the Natural History Society of Northumberland and Durham. He was credited with the discovery of the Intermediate Wintergreen (*Pyrola* media) and his name is commemorated in the genus *Winchia*.

Henry Thomas Maire Silvertop Witham (1779–1844)

Born Henry Silvertop (Fig. 3) at Minsteracres, County Durham, he married Eliza Witham of Headlam in 1801, a niece and co-heiress of William Witham of Cliffe, Yorkshire. On the death of her uncle, Eliza inherited the estate of Cliffe and Henry assumed the Witham name and coat of arms. They lived at Lartington Hall in Teesdale, which the Maire family had acquired by marriage in 1654. A wealthy man, he indulged in the pursuits of hunting and horse racing and mixed socially with other people of note, such as Sir Humphry Davy.

Figure 3 Henry Witham (Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).

OUGS Journal 35 (1–2) 2014, 29–56

© OUGS ISSN 0143-9472

** Every effort has been made to acknowledge the sources of all the figures. However, the unltimate sources for Figs 47, 54 and 64 could not be found.*

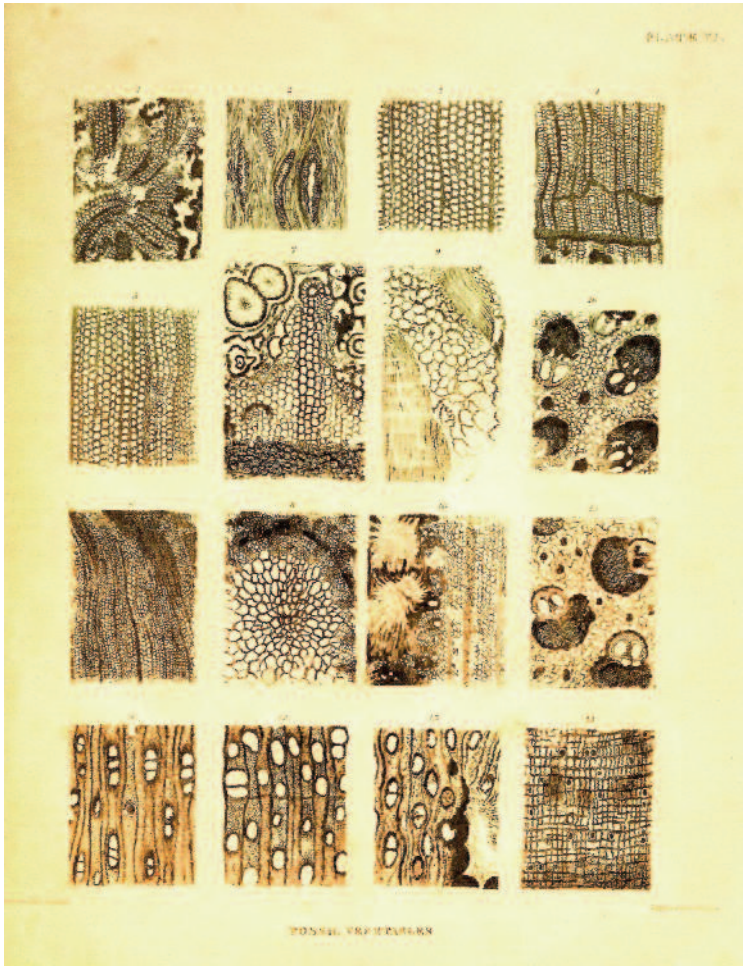


Figure 4 Thin sections from Observations on Fossil Vegetables *(Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

He had a great interest in geology and palaeobotany, of which he was a pioneer and was a founder-member and Vice-President of the Natural History Society of Northumberland and Durham. He was also a member of the Wernerian Natural History Society and the Royal Society of Edinburgh. He relied heavily on the work of other geologists in providing specimens of fossil plants and details of localities where he could collect specimens for himself.

In December 1829 Witham read his paper, 'On the vegetation of the first period of an ancient world', before the Wernerian Society. In Edinburgh he met and became friends with William Nicol, the inventor of the polarizing microscope (crossed Nicols), and learned of his technique for producing thin sections. Witham provided Nicol with many specimens to work on. At the time, the technique could take as much as three days to produce a thin section, which Nicol then posted to Witham with a preliminary identification. Nicol was not a wealthy man so it was Witham who then took matters further. He obtained the services of William MacGillivray, a leading Scottish naturalist (who provided illustrations for Audubon's *Ornithological Biography*), to produce detailed drawings of some of these sections. These illustrations were then used to produce six copper-plate etchings at a cost of about £500 per plate (£500 in the 1830s). Witham used these to illustrate his most notable publication, *Observations on Fossil Vegetables accompanied by Representations of their Internal Structure as seen through the Microscope* (1831). A total of 25 copies were produced of the first edition (one of which I have held)! (Fig. 4)

At this point relations between Nicol and Witham deteriorated. This first edition included an extremely grateful and sincere dedication to Nicol for his hard work, kindness and assistance. Nicol had, however, assumed co-authorship and was aggrieved that it carried only Witham's name. In his book Witham also described Nicol's thin section technique in such detail that it enabled others to set up businesses to supply thin sections to gentleman collectors. In 1832 Lindley and Hutton (*see below*) identified Witham in their book *Fossil Flora of Great Britain* as the pioneer of the thin section technique. To add insult to injury, Witham went on to produce an expanded second edition of *Observations on Fossil Vegetables* … in 1833, now entitled *The Internal Structure of Fossil Vegetables found in the Carboniferous and Oolitic Deposits of Great Britain* (which he dedicated to William Hutton), in which no reference was made to Nicol. Nicol only finally achieved recognition as the inventor of the technique in 1851, weeks after his death.

Outside his geological pursuits, Witham was a benevolent and generous person. Having spent several years in Edinburgh studying fossil plants, he returned to Lartington on the death of his mother in 1832. He founded the Barnard Castle Mechanics Institute and helped provide a Dispensary to the Sick and Poor. He provided facilities to educate the local 'working classes' (largely mill workers). Late in his life he expressed a wish that there were some permanent buildings where they could carry out that work. In 1838 more than 2,000 people subscribed to a ceremonial presentation (a clock) for Henry Witham. He became the first Roman Catholic High Sheriff of Durham in 1844 and died in December of that year. Following his death, local residents raised money to build the Witham Testimonial (now Witham Hall) in Barnard Castle, fulfilling his wish for somewhere to run the Mechanics Institute and Dispensary.

Witham's geological collection, formerly housed in a museum he had built at Lartington Hall, designed by Ignatius Bonomi in 1836, now resides within the vaults of the Natural History Museum of London and the British Geological Survey. He was the first to investigate several species of fossil tree, including *Pitus withami* (the Craigleith tree) and his interpretation of *Pitus* was that they were fossil gymnosperms and not vascular cryptograms, thus showing that gymnosperms were prevalent in Lower Carboniferous times. *Pitus* is now classed as a Pteridosperm.

Roderick Impey Murchison (1792–1871)

I wonder if many of you are surprised to see Murchison here among my collection of local geologists (Fig. 5). It was in my research for this article that I discovered his small but significant connections with north-east England, as I believed he was Scottish through and through. He was born in Tarradale House, Muir of Ord, Ross-shire but spent only his early years there. His father suffered from ill health after returning from a long period in India. They moved from Tarradale to the south of England in the hope that this would help improve

Figure 5 Sir Roderick Impey Murchison (Wikipedia, Public Domain).

FORMERLY
THE RESIDENCE OF
SIR RODERICK MURCHISON,
TWICE PRESIDENT OF THE ROYAL
GEOGRAPHICAL SOCIETY. HE DIED
IN 1871, AGED 79. A GREAT
GEOLOGIST AND EXPLORER, A TOWN
IN NEW ZEALAND, FALLS ON THE NILE,
A MOUNTAIN RANGE AND RIVER IN
AUSTRALIA AND A SOUND IN
GREENLAND ARE ALL NAMED
AFTER HIM.

Figure 6 Blue Plaque outside 21 Galgate, Barnard Castle; Murchison River in Australia has two tributaries — the Roderick and the Impey (© 2004–2009 Teesdale Marketing Ltd; reproduced with permission).

Murchison Snr's health, but this change did not avert the malady and he died in 1796, when Roderick was four years old. Roderick then moved to Edinburgh with his mother and brother. His mother married again, to Colonel Robert MacGregor Murray, whom she accompanied to Ireland when he was called to aid in suppressing rebellion there. Thus, at the age of seven Murchison was sent to Durham School, where he spent a not particularly studious six years. 'Dick' was a ringleader of the wayward boys at Durham, engaging in pranks such as crawling through a drain under Prebend's Bridge and climbing on the cathedral roof. His vacations were spent in Bedale in the North Riding, where he enjoyed pony riding and terriers; here he also began thinking of a military career.

In 1805 he was sent to the Military College at Great Marlow, where his lack of academic aptitude was noticed, as was his willingness to lead the boisterous youths astray. He did, however, show some promise in drawing and tactics. In 1808 he saw his first action when he landed in Galicia with Field Marshall Arthur Wellesley (later the Duke of Wellington) and was present at the actions of Roliça and Vimeiro. He also took part in the retreat to and final battle at Corunna.

After eight years service he left the army and, in 1814, married Charlotte Hugonin. There followed two years touring Europe, visiting the delights of Italy and France before returning home in 1818. Charlotte's grandfather had passed away and the empty house was chosen to be their first home. The property in question was an old mansion in Barnard Castle, where they spent much time entertaining the country folk of the neighbourhood. With little to occupy him, Murchison indulged wholeheartedly in field sports, becoming one of the best fox hunters in the north of England. Charlotte passed the time collecting plants and minerals. She also helped illustrate some of their neighbour Henry Witham's collection. Witham was also a keen fox hunter and would have accompanied Murchison on many occasions. They attended social gatherings at nearby Rokeby House where distinguished guests often appeared.

Still fixated on hunting, Murchison moved to Melton Mowbray in 1822 where he kept eight hunters, a horse for his wife and subscribed to a pack of hounds, but he soon tired of it. In 1823 he revisited Rokeby where he met Sir Humphry Davy and, while shooting partridge with him, perceived that he could pursue philosophy without abandoning field sports. Sir Humphry encouraged him to take up science and come to London, where he would get him into the Royal Society, a suggestion backed by Charlotte.

In 1824 they moved to London and Murchison attended lectures at the Royal Institution, where he found the subject of British geology of particular interest. He soon joined the Geological Society of London and in 1826 embarked on his first outing as a field geologist. The rest, as they say, is history. He went on to help define the Silurian and Permian systems, was one of the founders of the Royal Geographical Society in 1830, produced a work on Russia and the Ural Mountains in 1845, was knighted in 1846 and in later life spent much time working on the complexities of the Highlands of Scotland. He died at 16 Belgrave Square, Westminster in 1871 and is buried in Brompton Cemetery, London.

He remains the only person to have been President of both the Geological Society of London (twice) and the Royal Geographical Society (four times) (Fig. 6).

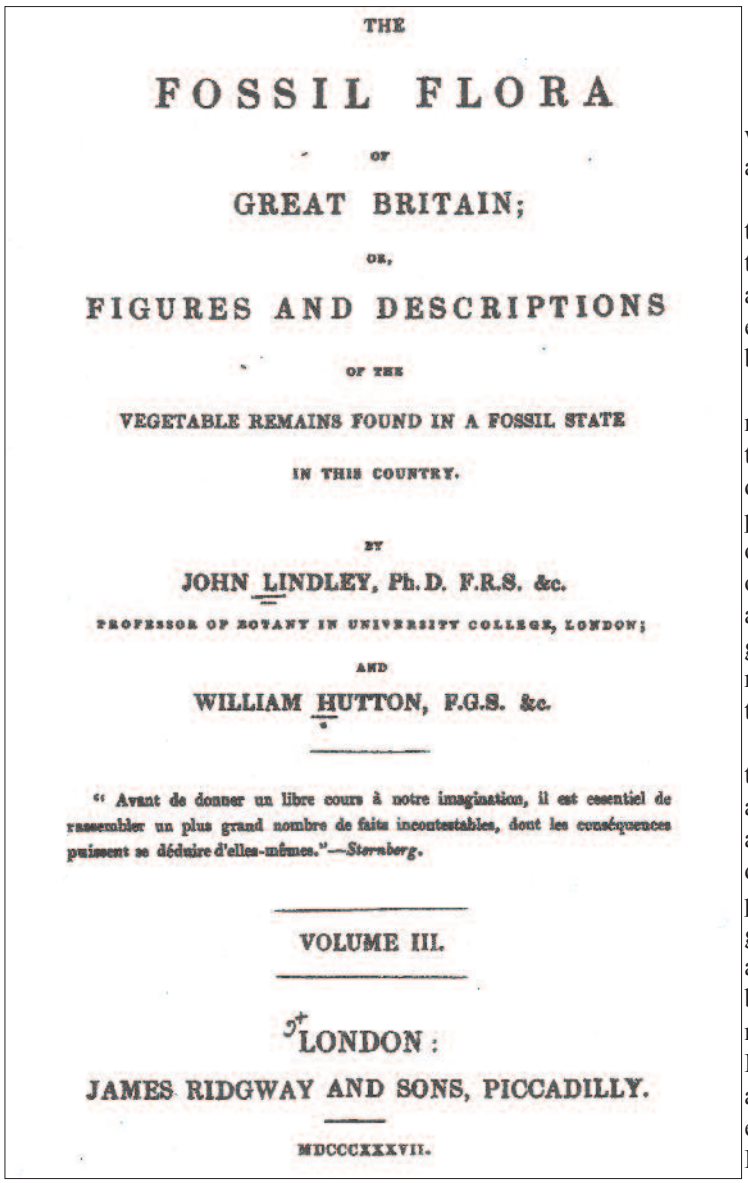
William Hutton (1797–1860)

Born in Sunderland, Hutton moved to Newcastle upon Tyne at an early age (Fig. 7). He worked as an agent of the Norwich Fire Insurance Company. He had little formal education, but by 1818 had joined the Literary and Philosophical Society of Newcastle upon Tyne and in 1825 the Society of Antiquaries of Newcastle upon Tyne. Already an honorary curator of the George Allan Museum, purchased by the Lit. and Phil. Society in 1822, Hutton had built up his own collection of minerals and fossil plants. He gained a reputation as a practical geologist, an expert on the coal measures and an ardent collector of fossils from the coal measures. This was no doubt facilitated by his friendship with John Buddle, a Kyo-born (County Durham) colliery viewer, manager of Wallsend Colliery and a pioneer of mining engineering — he contributed to the development of and tested the new Davy lamp on its first 'real' trial in 1835, and was also responsible for building Seaham Harbour.

Figure 7 William Hutton (BBC Your paintings / Public Catalogue Foundation).

Regarding Hutton, it was said that, "The fossils of our coal-fields first found an exponent in him." He became a Fellow of the Geological Society of London in 1828 and helped found the Natural History Society of Northumberland and Durham in 1829, acting as their secretary and curator. From 1830 to 1835 he was co-Secretary of the Newcastle Literary, Scientific and Mechanical Institution, and Vice-President from 1835. His most notable contribution was to palaeobotany, publishing the three-volume monograph, *The Fossil Flora of Great Britain*, co-authored with John Lindley between 1831 and 1837. This work contains illustrations of 200 species and was dedicated to Roderick Impey Murchison, an undertaking so arduous that Lindley gave up palaeobotany on its completion (Fig. 8, *overleaf*).

The fossil plant *Huttonia* was named after him by Sternberg in 1837 in recognition of his achievements, and he was made a



THE

FOSSIL FLORA

OF

GREAT BRITAIN;

OR,

FIGURES AND DESCRIPTIONS

OF THE

VEGETABLE REMAINS FOUND IN A FOSSIL STATE

IN THIS COUNTRY.

BY

JOHN LINDLEY, Ph.D. F.R.S. &c.

PROFESSOR OF BOTANY IN UNIVERSITY COLLEGE, LONDON;

AND

WILLIAM HUTTON, F.G.S. &c.

"Avant de donner un libre cours à notre imagination, il est essentiel de rassembler un plus grand nombre de faits incontestables, dont les conséquences puissent se déduire d'elles-mêmes."—*Sternberg.*

VOLUME III.

LONDON:

JAMES RIDGWAY AND SONS, PICCADILLY.

MDCCCXXXVII.

Figure 8 Front page from The Fossil Flora of Great Britain *(Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

Fellow of the Royal Society in 1840. Hutton took on the post of treasurer at the Natural History Society in 1845 in addition to his other roles. The extra workload may have contributed to the poor health he suffered the following year. In 1846 he left Britain to live in Malta, but returned to Newcastle in 1851 before later moving to West Hartlepool. There he was involved with the local Literary and Mechanics Institution and the plan to establish a museum at the Athaenaeum. He died there in 1860.

In 1877 Professor G. A. Lebour edited, from Hutton and Lindley's papers, the work *Illustrations of Fossil Plants*, published for the North of England Institute of Mining and Mechanical Engineers. Hutton's valuable collection of fossils passed to the council of the Mining Institute, but was then transferred to the museums of the Natural History Society of Northumberland and to Durham College of Physical Science (later Armstrong College).

George Tate (1805–1871)

George Tate (Fig. 9) was born on 21 May 1805, the eldest son of Ralph Tate, a builder and Freeman of Alnwick. Educated at the Grammar School in Alnwick, he went on to serve an apprenticeship as a draper in Alnwick Market Place. He and his brother, Thomas Turner Tate, were members of a local debating society, where George learned the art of expressing his opinions fluently and with ease.

On completing his apprenticeship he was required to go through 'the well' in order to become a Freeman of the town, a tradition thought to date back to King John, who became stuck in a bog while hunting on Alnwick Moor. He then ordained that every candidate for Freeman status had to pass through the same bog on the anniversary of his own mishap.

Tate began his business in 1826, which grew rapidly, but was not his sole interest. In 1828 he became one of the Secretaries of the Mechanics' Institution at Alnwick, to which he boosted attendance by banishing atheistic and polemical discussion and by promoting scientific knowledge among its members. He called on literary and scientific friends to deliver lectures and on many occasions presented talks himself. These included such subjects as 'On the formation of dew', 'The succession of life upon the globe', 'Causes and effects of high tides' and 'The minerals and rocks of Northumberland'. He went on to be Secretary for more than 30 years, retiring in 1859.

He married in 1832 and his wife, Ann, helped in the business to such an extent that George was able to devote more time to antiquarian and scientific research. On 6 March 1841 he was appointed Postmaster at Alnwick (less than a year after the introduction of the Penny Black stamp). Ann died in 1847, at which point George turned his energies toward his business, but then gradually regained interest in his former studies and, in 1855, abandoned business and returned to science. He was a strong believer in education and welfare and in 1849 attended preliminary enquiries of the Government Inspector prior to the Public Health Act being put into operation; and in 1850 he was elected as a member of the first Board of Health, where he advocated extensive measures of sanitary reform. He retained his seat on the Board until his death.

In 1869 a Club was formed in Alnwick to promote scientific research. George Tate was duly elected President and proceeded to attend a trip to Howick, where he described the interesting section of strata near Cullernose. George Tate's interest in geology had begun about 1832, when the science was in its infancy and when there was little literature on the subject. The publication of Charles Lyell's *Principles of Geology* inspired Tate to commence a series of geological investigations into the area around Alnwick. He then went on to study Northumberland, Durham and parts of Berwickshire. His early investigations were of the Carboniferous and Mountain Limestone formations, upon which he illustrated and lectured. His collection of fossils

Figure 9 George Tate (Biodiversity Heritage Library).

included unique specimens, three species of which were subsequently named after him by Professor T. Rupert Jones: *Estheria striata* var. *Tateana*, *Candona Tateana* and *Beyrichia Tatei*). In 1869 he exhibited part of his collection at the Corn Exchange in Alnwick.

Tate was elected a Fellow of the Geological Society of London, an Honorary Member of the Hastings and Newcastle upon Tyne Literary and Philosophical Societies, and an Associate of the Edinburgh Geological Society. Among his many discoveries, he was the first to notice the marks of ice action on the rocks of Northumberland, at Hawkhill Farm near Alnwick. Here he observed polished, scratched and grooved surfaces on limestone beneath the boulder clay. In 1855 he embarked on a tour from the Vale of Whittingham to the River Tweed to investigate the rocks lying between the Red Conglomerates and the Mountain Limestone. He discovered that the mineral character and organic remains within the strata differed from the Mountain Limestone with which they had been previously grouped. Because the rocks were so largely developed on the Tweed he applied the term 'Tuedian' to the group in 1856.

The following year Tate set out on another geological tour, this time from Bowness to Wallsend, publishing his antiquarian and geological findings in Dr Bruce's work *Roman Wall* (1867), and within which he confirmed the intrusive nature of the Whin Sill, first postulated by Sedgwick in 1827 but later considered to be a lava flow by Phillips and W. Hutton.

George Tate was not an advocate of Darwin. Although accepting Darwin's arguments were extensive and powerful, he believed in man's divine origin, declaring, "For, in his origin he cannot be linked with any of the creatures which preceded; for, whatever modifications of bodily form may be made by physical conditions, natural selection, or any secondary law, such is the great gulf between the highest brute and man, that we can refer the introduction of an intellectual and moral being, capable of generalising and of indefinite progression, and endowed with a sense of responsibility, to no other than to the divine Sovereignity."

His antiquarian works include an account of the 'Sculptured Rocks of Northumberland' and, his most notable publication, the *History of Alnwick*, was completed in 1868. This work was regarded so highly that a public banquet was held in his honour in the Alnwick Town Hall, at which he was presented with a beautifully illuminated address, a purse of gold and an elegant silver tea and coffee service. A measure of the man was his response that he, "had intended that his *opus magnum* should be the Geology of Northumberland; but that at his age, with infirm health, he could not hope to accomplish it."

Tate suffered from chronic asthma and was confined to his room for several months of the year. At these times he concentrated on his museum, working on specimens collected during his summer investigations. The winters of 1869 and 1870 had a particularly severe impact on his health, yet he was still able to read a paper 'On the basaltic rocks of Northumberland', to members of the Alnwick Scientific Research Club at his home; and he continued to prepare and issue circulars for the Berwickshire Naturalists and Field Club despite his failing health. George Tate died in the early hours on Wednesday, 7 June 1871, at his home in Alnwick. His funeral took place on 9 June with many in attendance. In Alnwick the shops were partially closed and blinds drawn as the procession made its way towards the Parish Church of St Michael, where he was laid to rest alongside the grave of his wife.

Tate's geological legacy lived on in his nephew, Ralph Tate (1840–1901), to whom he taught geology from an early age. Ralph Tate went on to work for the Geological Society of London and published work on the Yorkshire Lias before becoming the first President of the Royal Society of South Australia in 1880.

The pioneering geologists described above were near contemporaries, and would have known each other, been members of the same societies and known about each other's work. This is particularly true of William King and Richard Howse, who not only were in the same societies but shared the same special interest in Permian fossils. Both were also curators of the Natural History Society of Northumberland, Durham and Newcastle upon Tyne. The were, however, of very different personalities.

William King (1809–1886)

William King (Fig. 10) was born in Low Row, Bishopwearmouth, Sunderland in 1809, the son of a 'fish carrier'. He attended a good school adjoining and belonging to the old Zion Chapel in Moor Street, Sunderland. He had an inquiring disposition and delighted in wandering along the shore or into the country and collecting stones, shells or other objects along the way.

Figure 10 William King (Ancestry.co.uk website; public member info).

In 1833 he married Jane Nicholson at Jarrow and opened a bookshop at 205 High Street West, Sunderland, which became a meeting place for Sunderland academics. Around this time he became Secretary and Librarian to the Sunderland Literary and Philosophical Society. From 1837 to 1840 he was the first Curator of the Sunderland Natural History and Antiquarian Society (now Sunderland Museum).

In 1840 King was appointed Curator of the Newcastle Museum (then next to the Central Station), which belonged to the Natural History Society of Northumberland, Durham and Newcastle upon Tyne. Before this appointment he was not a member of the society but would have been well known in geological circles. The Society raised subscriptions to pay for the curator, and to take up this post, King and his family left Sunderland and moved to Collingwood Street, Newcastle. In addition to being Curator, he also gave lectures and offered specimens as gifts. The Society also bought specimens from him.

King studied anatomy and specialised in the fossils of the Permian Magnesian Limestone. He collected, described and sketched many specimens, including new ones obtained from the rocks of Northumberland and Durham. Always eager to acquire new examples, he also obtained specimens from another local collector, Richard Howse (*see below*), with whom he communicated on a regular basis.

In 1846 King presented a catalogue of these fossils to the Tyneside Naturalists' Field Club. He drew up an advertisement for his *Catalogue of Organic Remains of the Permien Rocks of Northumberland and Durham*, which the Field Club advertised, at his request, on the cover of the *London Geological Journal* No. II, 1847. King had made arrangements with the printer for publication of the catalogue, but then, in May 1847, withdrew it from the

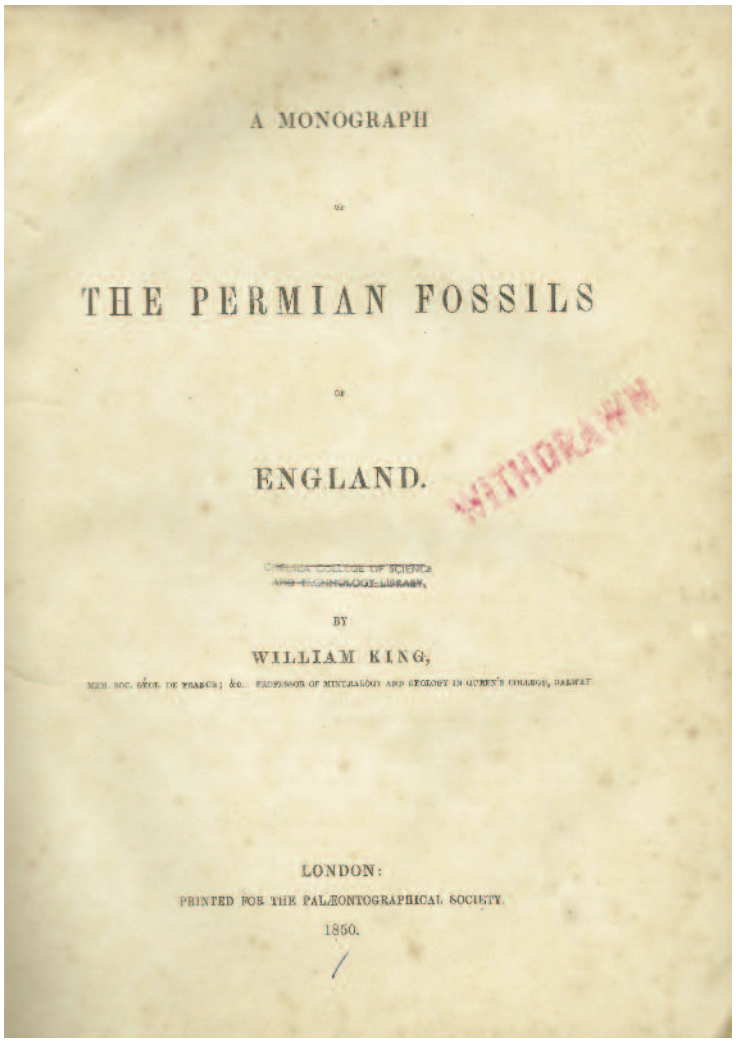
printing office. No notice or reason for its withdrawal was given to the Field Club Committee, but in July of that year the printer informed the Club Secretary that King had withdrawn his catalogue. The Secretary then wrote to King asking for confirmation of this, to which King replied with only a terse, penciled 'Yes'.

Feeling obliged to produce a catalogue, having already advertised one, the Committee then contacted Richard Howse, asking if he could produce one for them from his own extensive collection. Howse agreed and his *Catalogue of the Fossils of the Permian System of the Counties of Northumberland and Durham* was duly advertised in the *Newcastle Chronicle* of August 11, 1848, and published on 17 August 1848. Within days of Howse's catalogue being advertised, King announced that his catalogue would be published immediately. Nevertheless, King's catalogue appeared some two days after Howse's, after which an intense argument ensued over 'priority', particularly regarding the description and naming of new species (Fig. 11). In the midst of this on November 10, 1847 King dramatically left his job as Curator after being accused of inappropriate behavior. He was selling geological specimens, which he considered to be part of his private collection, but which the Society regarded as theirs!

This controversy hardly seems to have been a setback to King's career, as by 1849 he had become a Fellow of the Geological Society of France before being appointed to the Chair of Mineralogy and Geology at the newly formed Queen's College, Galway, Ireland, his application including a reference from Charles Lyell. The following year King produced his most noted work, *A Monograph of the Permian Fossils of England*, drawing on the work he had already carried out for his earlier publication. The beautiful sketches in this monograph are the work of G. B. Sowerby (Fig. 12). It also includes a chronological 'List of works referred to' where he lists his own catalogue before that of Howse!

King brought with him to Galway part of his collection of rocks and fossils and established a geological museum at the Galway College in 1852 (now called the James Mitchell Museum). That same year his son, also William, studied geology under his father at Queen's College. William Jnr went on to be the Director of the Geological Survey of India.

The discovery by quarry workers of bones in a cave in the Neander Valley, Germany in 1856 led ultimately to William King Snr's most recognised achievement. It was King who pointed out that the sediments in the cave where the bones were found were at least 30,000 years old. In a paper read at the annual meeting of the British Association in 1863, which took place in Newcastle upon Tyne that year, referring to the skull, King was "constrained to believe that the thoughts and feelings which once dwelt within it never soared above those of a brute. Thus the author is led to regard the Neanderthal skull as belonging to a creature cranially and physically different from man; and he proposes to distinguish the species by the name of *Homo neanderthalensis*" (Fig. 13, *opposite*). A fuller explanation of his research and findings appeared in the *Quarterly Journal of Science* Vol. 1 (1864), in which he reflected on his naming of *Homo neanderthalensis*,


A MONOGRAPH

ON THE

PERMIAN FOSSILS

OF

ENGLAND.

WITHDRAWN
QUEEN'S COLLEGE OF SCIENCE AND TECHNOLOGY LIBRARY

BY

WILLIAM KING,

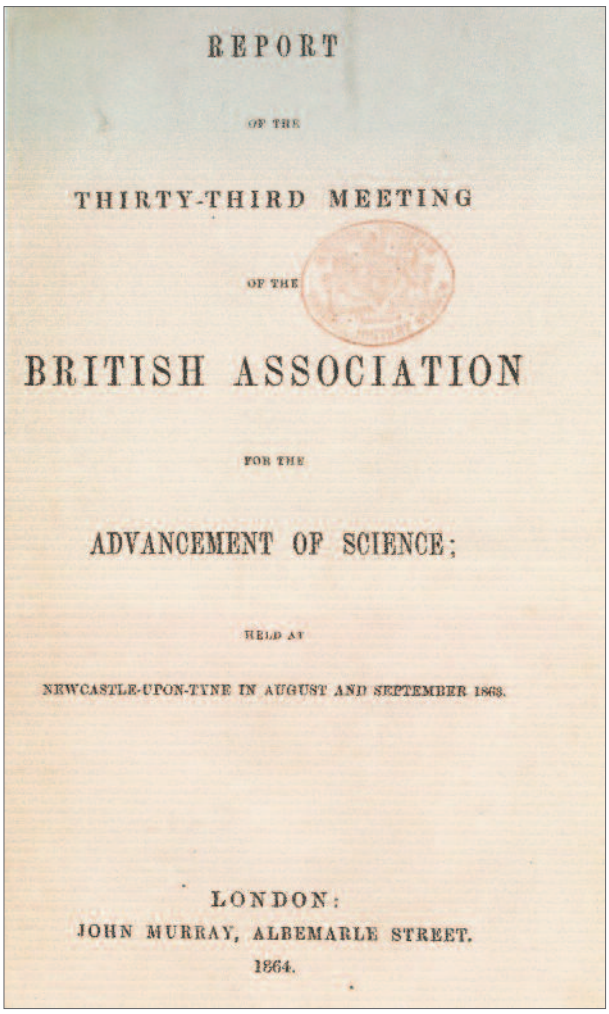
MEM. SOC. GÉOL. DE FRANCE; &c., PROFESSOR OF MINERALOGY AND GEOLOGY IN QUEEN'S COLLEGE, GALWAY.

LONDON:

PRINTED FOR THE PALÆONTOGRAPHICAL SOCIETY.

1850.

Figure 11 Front page of King's Permian Monograph (1850).
Figure 12 Plate III from King's 'Monograph'. (Both figures author scans.)



REPORT

OF THE

THIRTY-THIRD MEETING

OF THE

BRITISH ASSOCIATION

FOR THE

ADVANCEMENT OF SCIENCE;

HELD AT

NEWCASTLE-UPON-TYNE IN AUGUST AND SEPTEMBER 1863.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1864.

Figure 13 First naming of Homo neanderthalensis *(Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

stating, "but I now feel strongly inclined to believe that it is not only specifically but generically distinct from Man."

King, along with Thomas Rowney, Professor of Chemistry at Galway, went on to disprove the putative fossil Eozoon canadense that, at the time (1865), was thought to be the world's earliest living thing. King discussed, with variable degrees of success, the economic geology of Ireland, the development of cleavage in Donegal, uplift of the Burren, and even acted as a consultant for the route of transatlantic cables (Fig. 14).

William King and his son were awarded honorary DScs by Queen's University Galway in 1882. In his later years he was a rather anonymous figure in the geological community and died at his home in Glenoir, Galway on 23 June 1886.

Figure 14 King at University College, Galway (Wikimedia, Creative Commons).

An inscribed plaque on the south-facing wall of James Mitchell Museum, University College Galway reads:

Geology treats of the (1) materials, intimate structure, order of position, and origin of rocks, comprising the crust of the globe (mineralogy, petrology & stratigraphy), — (2) of the physical changes which the surface of the Earth has undergone and is now undergoing (physical geography), — (3) and of the various plant and animals which have tenanted the lands and waters of by-gone periods as well as the order of creation (palaeontology).
Professor William King

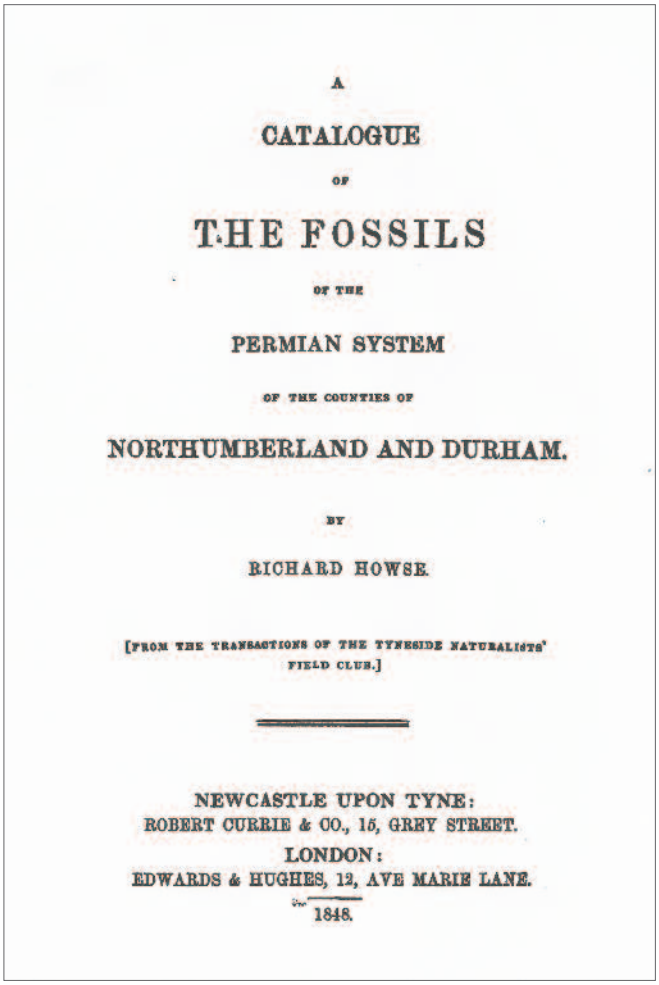
Richard Howse (1821–1901)

Richard Howse was born in Thame, Oxfordshire in 1821, son of an Inland Revenue Officer. Much of his childhood was spent collecting shells, birds, eggs and, especially, fossils, which were plentiful around Thame. By 1841 his family had moved to north-east England, Richard joining them and establishing himself as a private tutor in South Shields. While teaching for a living he continued his study of the natural objects of land and sea, which became the main interest in his life.

Howse could not be regarded as a specialist, as he botanised, geologised, dredged, collected fossils and other specimens almost universally. When William King left his position as Curator of the Newcastle Museum in 1847, he was succeeded in that role by Howse, who moved to Trafalgar Street, Newcastle to be closer to the museum, but also continued to be a private tutor. One of his first tasks was to complete his *Catalogue of the Fossils of the Permian System of the Counties of Northumberland and Durham* for the Tyneside Naturalist's Field Club in the absence of King's advertised catalogue (Fig. 15).

Before Howse's catalogue was published, lists of Magnesian Limestone fossils of the area had previously appeared in Winch's 'Observations on the geology of Northumberland and Durham' (9 species) (1817), in Sedgwick's 'On the geological relations and internal structure of the Magnesian Limestone' (33 species)

Figure 15 Front page of Howse's Permian Catalogue *(1848) (Biodiversity Heritage Library, not in copyright).*



A

CATALOGUE

OF

THE FOSSILS

OF THE

PERMIAN SYSTEM

OF THE COUNTIES OF

NORTHUMBERLAND AND DURHAM.

BY

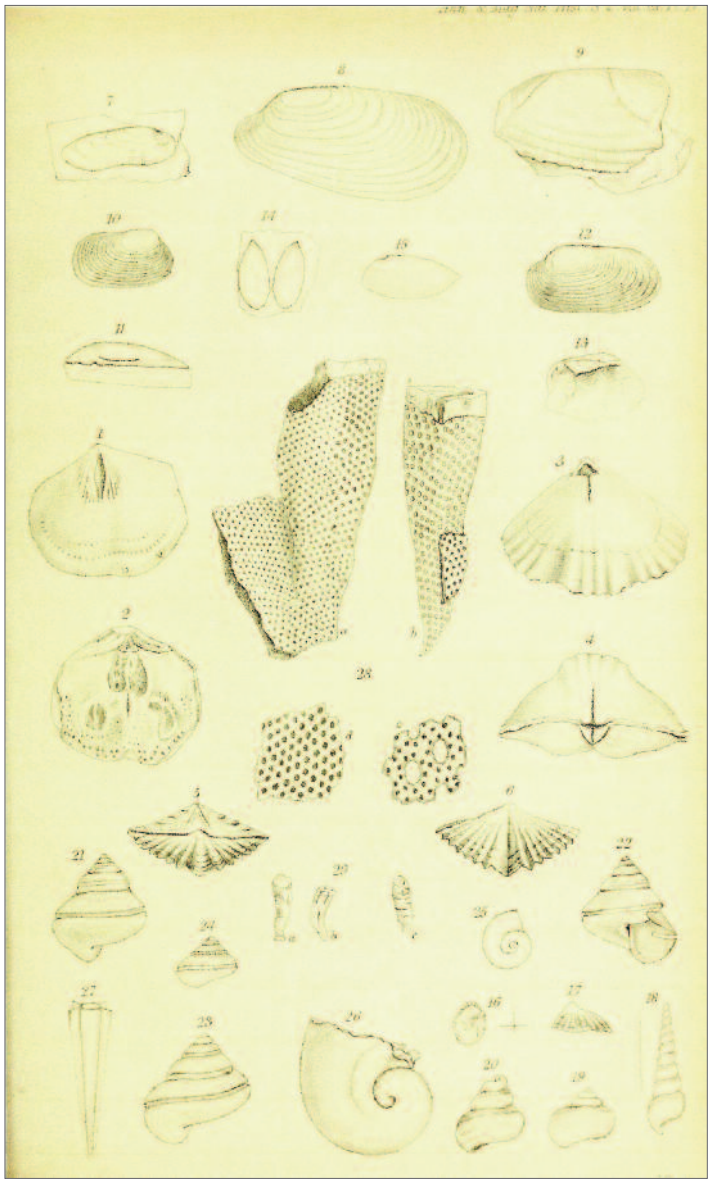
RICHARD HOWSE.

[FROM THE TRANSACTIONS OF THE TYNESIDE NATURALISTS' FIELD CLUB.]

NEWCASTLE UPON TYNE:
ROBERT CURRIE & CO., 15, GREY STREET.
LONDON:
EDWARDS & HUGHES, 12, AVE MARIE LANE.
1848.

(1829), and in Murchison *et al.* 'Geology of Russia in Europe and the Ural Mountains' (58 species) (1845). Descriptions in the first two lists were so vague as to leave it impossible to recognise the species described. Although Murchison's publication had more in the way of description (including reference to the work of William King), detail was not always specific. Also, owing to the work of King and Howse, many more previously unidentified specimens had recently been found. As a result, Howse's catalogue included detailed descriptions of 83 species from the Permian of the region, but, sadly, without drawings.

Howse produced an update to his catalogue in his *Notes on the Permian System of the Counties of Northumberland and Durham* in 1857, in which he added several species to the fossil list as well as correcting inaccuracies in his earlier catalogue, as well as inaccuracies in the works of King and Geinitz, which had appeared since Howse's 1848 publication. In this update he produced one plate of his sketches, not up to Sowerby's standard sadly (Fig. 16). Many of his corrections relate to King's 'Permian Monograph', for Howse did not agree with some of the species separations King made. Howse believed many to be simply form variations or juvenile individuals of other species. He also points out King's description of a new species where no type specimen exists, as King had 'mislaid' his samples!



Despite 10 years having passed since Howse was requested to produce his catalogue, and because King still had issues over misrepresentation, Howse felt the need to put forward his claim for priority over King's subsequent publication (in which King had made charges against Howse). At the end of Howse's *Notes on the Permian System* he goes to great lengths to defend his claim to priority, including details of communications he received from King before publication.

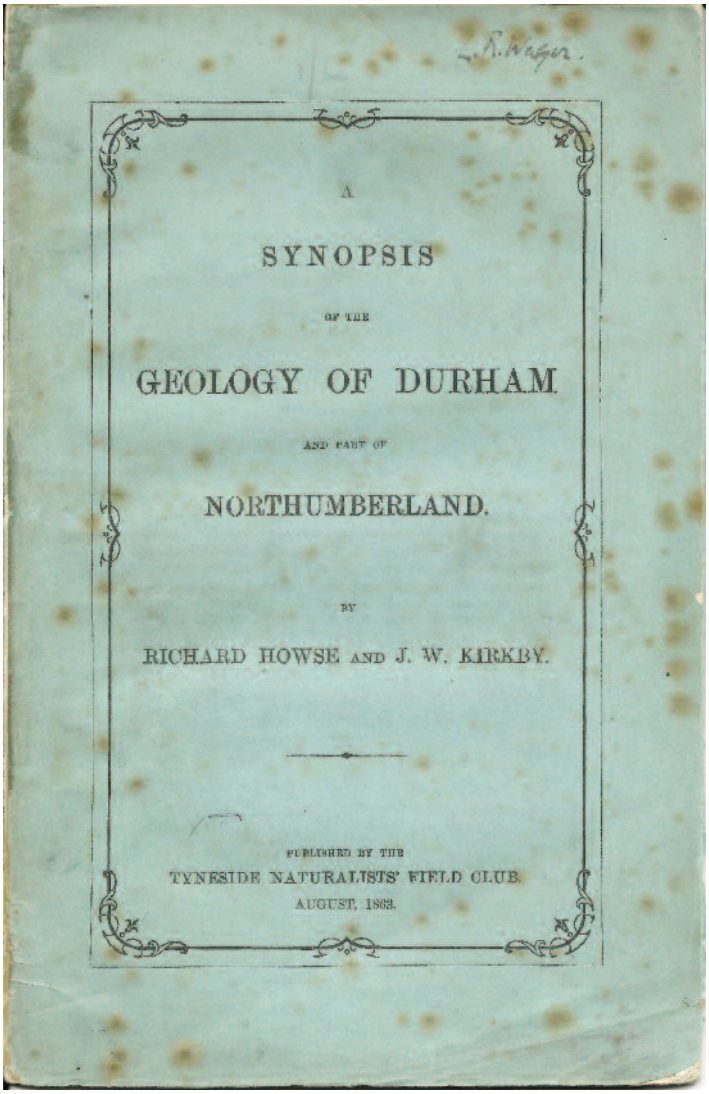
For it seems that after King advertised his version of the catalogue, Howse discovered that King had requested proof sheets of Howse's catalogue from the printers, just two days before publication. Howse determined to find out the exact date of King's publication and obtained from the printer's records the following entry: "Aug. 18, 1848. 200 of Mr King's pamphlets." This is the day after Howse's catalogue appeared. In addition, he was informed that King's pamphlet would not have been finished ('stitching' and 'doing up') until the following day — August 19th. Howse repeatedly tried to buy a copy of King's catalogue and could not get one until the afternoon of August 19th, the bookseller recording two entries of sale on that date. This detailed information proved Howse's priority by two days.

Extracts of King's letters to Howse between December 1844 and November 1845 show that King was constantly requesting Howse to bring over or send him anything new he had found in the Magnesian Limestone. He also requested that Howse provide him with sketches. Howse goes on to state that "Mr. King never made any communication, either personally or by letter, except when he wished to gain some opinions or information; and these, if they suited his purpose, he without compunction published as his own." An extreme example of this is highlighted by a passage from King that appeared in the *London Geological Journal* Vol 1, p10. *Note* – "I am happy to add that within the last few days I have discovered in the collection of Mr Howse, a magnesian limestone *Solemya* resembling *S. primeva*." It appears the specimen was taken by King without permission. The specimen in question was, at the time, unique, found by Howse at Humbleton Hill on Good Friday, 1845. Howse described it in the Tyneside Catalogue and named it *S. normalis*. He wondered how King dare to identify the shell in his Permian Monograph with the 'uncharacterised' name *S. Phillipsiana*, and even include a (poor) sketch, having no specimen on which to base it. Howse accuses King of passing 'fictitious' names on the scientific world. King appears to have received or 'borrowed' many new species from Howse, which he subsequently identified as his own discoveries.

Richard Howse was not only a collector, he also did a considerable amount of original mapping, particularly of Weardale and Redesdale, long before the Ordnance Geological Survey was established in 1835. He contributed to many publications, notably to the *Synsopsis of the Geology of Durham and part of Northumberland*, written jointly with Sunderland born J. W. Kirkby, for the British Association in 1863 (Fig. 17, *opposite*). He also produced catalogues of the Hutton Collection of fossil plants, the Carboniferous rocks in the museum and another on fishes.

Much of this work took place while Howse was Curator at the cramped and crowded old Newcastle [Natural History] Museum in the south of the city, where many specimens were hidden away.

Figure 16 Plate from Notes on the Permian System *(1857) (Biodiversity Heritage Library, not in copyright).*


A

SYNOPSIS

OF THE

GEOLOGY OF DURHAM

AND PART OF

NORTHUMBERLAND.

BY

RICHARD HOWSE AND J. W. KIRKBY.

PUBLISHED BY THE

TYNESIDE NATURALISTS' FIELD CLUB.

AUGUST, 1863.

Figure 17 Cover of Geology of Durham *(1863) (author scan).*

How pleased he must have been that the Natural History Society, under the direction of John Hancock (and support of Lord Armstrong) embarked upon the construction of a new building to the north of the city on Barras Bridge (costing £42,000). This new Museum of Natural History was opened by the Prince of Wales on 20 August 1884. Howse and his assistant, Mr Joseph Wright, carried out the removal of the specimens to their new home and their entire rearrangement, including the geological specimens in the 100ft × 40ft third hall at the Hancock Museum (which the museum was renamed in 1891 following the death of John Hancock).

By the 1890s, Howse was able to give up teaching and concentrate on his work at the museum. In addition to being Curator he was ex-officio editor of the joint *Transactions of the Natural History Society and Tyneside Naturalists' Field Club* and, for many years, was an Honorary Secretary of the latter.

Howse was essentially a practical and original worker, overflowing with information and a will to help other workers. He was, however, slow to publish and a shy person, which often prevented him from taking a prominent part on public occasions.

His death in February 1901 at 12 St Thomas Crescent, Newcastle upon Tyne, marked the end of the link with the founders of the Natural History Society and much of his knowledge died with him. He appears to have left no manuscripts and many undescribed specimens remained (and are still stored) at the Hancock Museum. Towards the end of his life he was awarded an honorary degree (MA) by the University of Durham. In 1963 the lamp shell discovered by Howse in the Permian Magnesian Limestone at Dalton-le-Dale and named by him in his 1848 catalogue as *Productus latirostratus* (but named *P. umbonillatus* by King!) was assigned to a new genus and renamed *Howseia latirostrata* (Fig. 18).

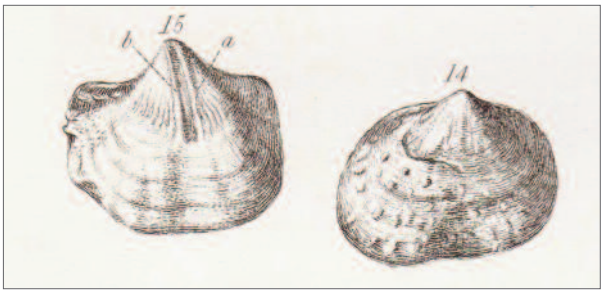


Figure 18 Howseia (Productus) latirostrata*, Plate XI in King's Permian Monograph (1850) (author scan).*

Another group of Northumbrian geologists studied geology at a variety of academic institutions and all had careers, including employment with the Ordnance Geological Survey. None were born locally but all spent some of their life carrying out survey work in north-east England. They are the authors of many of the memoirs on Northumberland and Durham geology, offering the most detailed information to date on much of north-east England, but sadly without grid references!

William Gunn (1837–1902)

William Gunn was born on 27 September 1837 in the village of Wheatley, near Cuddesdon, Oxfordshire, the son of John Gunn, an agricultural labourer, and his wife Thomasine (Fig. 19). In 1859 he married Sarah Firth in the Parish Church of St George, Hanover Square, Mayfair, London. He spent several years in teaching, initially in Chipping Campden, Gloucestershire, where he and Sarah lived for only a few years before moving to Newtown, Montgomery in Wales. During his leisure time he developed his knowledge of geology and botany.

Figure 19 William Gunn (NERC BGS GeoScenic).

In 1867 Gunn joined the Ordnance Geological Survey as an Assistant Geologist under Roderick Murchison at a time of expansion for the Survey. He spent his early professional career mapping large areas of the six northern counties of England, moving to Blackburn, Lancashire and contributing to the memoir on the Burnley Coalfield — not published until 1875, as with many of these early memoirs some years after the work was done. He was chiefly occupied, however, in surveying the Carboniferous rocks of West Yorkshire, Durham and Northumberland. During this time he based himself initially at Hawthorne Cottage, Cotherstone, Middleton-in Teesdale and then later at West Street, Berwick-upon-Tweed. In 1876 he became a Fellow of the Geological Society of London and in 1879 joined the Berwickshire Naturalists' Club. Over a period of about 15 years in north-east England he authored or co-authored four Geological Survey memoirs for the region: *The Geology of*

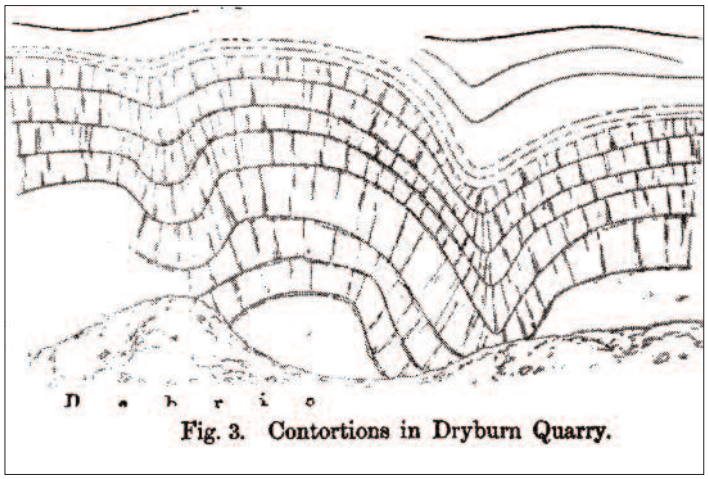


Figure 20 Sketch from Gunn's Geology of Belford… *memoir (1900, Fig. 3) (author scan).*

The Bandits Lair.
The names of those desperadoes are, reading from left to right,
Back row – J.B.Hill; Lw.Hinxman; J.Horne; G.Barrow.
Front row – J.Linn; B.N.Peach; H.Miller; W.Gunn.

Figure 21 'The Bandits of Inchna-damph, or the Secret of the North-West Highlands' (NERC BGS GeoScenic).

Part of Northumberland Including the Country between Wooler and Coldstream (with C. T. Clough; 1895), *The Geology of the Coast South of Berwick-upon-Tweed* (1897), *The Geology of the Country between Norham and Tweedmouth in Northumberland* (1897) and *The Geology of Belford, Holy Island and the Farne Islands, Northumberland* (1900) (Fig. 20). This involved surveying some 270 square miles of north Northumberland for the one-inch scale maps under the supervision of H. H. Howell, Director of the Geological Survey of Scotland, and at the instruction of Archibald Geikie, Director of the Geological Survey. He still found time to contribute articles to the Berwickshire Naturalists' Club, including ones on shells in boulder clay at Berwick and sculptured stones near Chatton. Gunn acquired an intimate knowledge of the Lower Carboniferous rocks and their gradual modification moving northwards to Scotland. The relations between the lithic subdivisions had proved difficult to understand for many years. Gunn's work contributed to his paper 'The correlation of the Lower Carboniferous rocks of England & Scotland', published in the *Transactions of the Edinburgh Geological Society* for 1898, which helped address this problem.

Although Sir Archibald Geikie became Director-General Geological Survey in London in 1882, he still had control over the Scottish Highlands work. It was his ambition to have the primary survey of Britain completed within his time in office. Unfortunately the survey of the Scottish Highlands was proving difficult and he resorted to having some of the survey work done at the one-inch scale. This did not record the geology in sufficient detail, however, so Geikie took a new approach. In 1884 he started transferring staff from northern England, where surveying was almost complete, and moved them to the Scottish staff. These transfers included Gunn, who was promoted to the rank of Geologist. Gunn moved to 22 Claremont Crescent, Edinburgh, where he lived for the rest of his life.

He went on to survey Bute, the Cumbraes, the North West Highlands (with B. N. Peach, J. Horne *et al.*, who became known as 'The Bandits of Inchnadamph, or the Secret of the North-West Highlands'; Fig. 21) and, in later years, Arran, where he was the first to prove the existence of the Tertiary vent there. He was appointed District Geologist in 1901 and, reaching the age of 65, retired in September the following year. He died suddenly on 22 October1902 from pulmonary embolism following subacute phlebitis.

George Alexander Louis Lebour (1847–1918)

Figure 22 George Alexander Louis Lebour (NERC BGS GeoScenic).

George Lebour was born in St Omer, Pas-de-Calais, France on 17 February 1847 (Fig. 22). He was the son of Alexander Xavier Lebour, a renowned artist, and Emilie Sophia Josephine Dorcy, a Professor of Languages. His parents brought him to England at the age of two to escape the 1848 revolution in France that ended the constitutional monarchy of Louis-Philippe. They settled in Kensington, London, where George was educated under the direction of his mother. His interest in literature, art and music began early in his life and stayed with him throughout it. As a child he was a keen collector of natural objects, out of which developed his ambition to become a geologist; but, on leaving school, his first employment was at a mercantile house in the City. He disliked the work and was eventually permitted to pursue the career he desired. He entered the Royal School of Mines in Jermyn Street, where he was influenced by the physicist John Tyndall, the biologist Thomas Huxley, the geologist Andrew Ramsay, and other leading scientists of the day.

In 1867 he joined the Ordnance Geological Survey, working with William Topley in Morpeth, Northumberland. He became a Fellow of the Geological Society of London and in 1870, and married his childhood friend, Emily Nona, daughter of London surgeon Dr William Hodding. Topley and Lebour worked on the Whin Sill escarpment, among other formations, and finally established the intrusive nature of the Whin Sill, largely based on the work of George Tate (*see above*). With Topley, he wrote a much-quoted paper 'On the intrusive character of the Whin Sill of Northumberland' (1877 *Quart J Geol Soc* **33**). Lebour stated that had Tate's work been published more widely than only in local society transactions, the matter would have been settled many years earlier (Fig. 23, *opposite*).

In 1873 Lebour left the Geological Survey and entered into practice as a consulting geologist. Two years later he was appointed Lecturer in Geological Surveying at Durham College of Physical Science in Newcastle upon Tyne (later, Armstrong

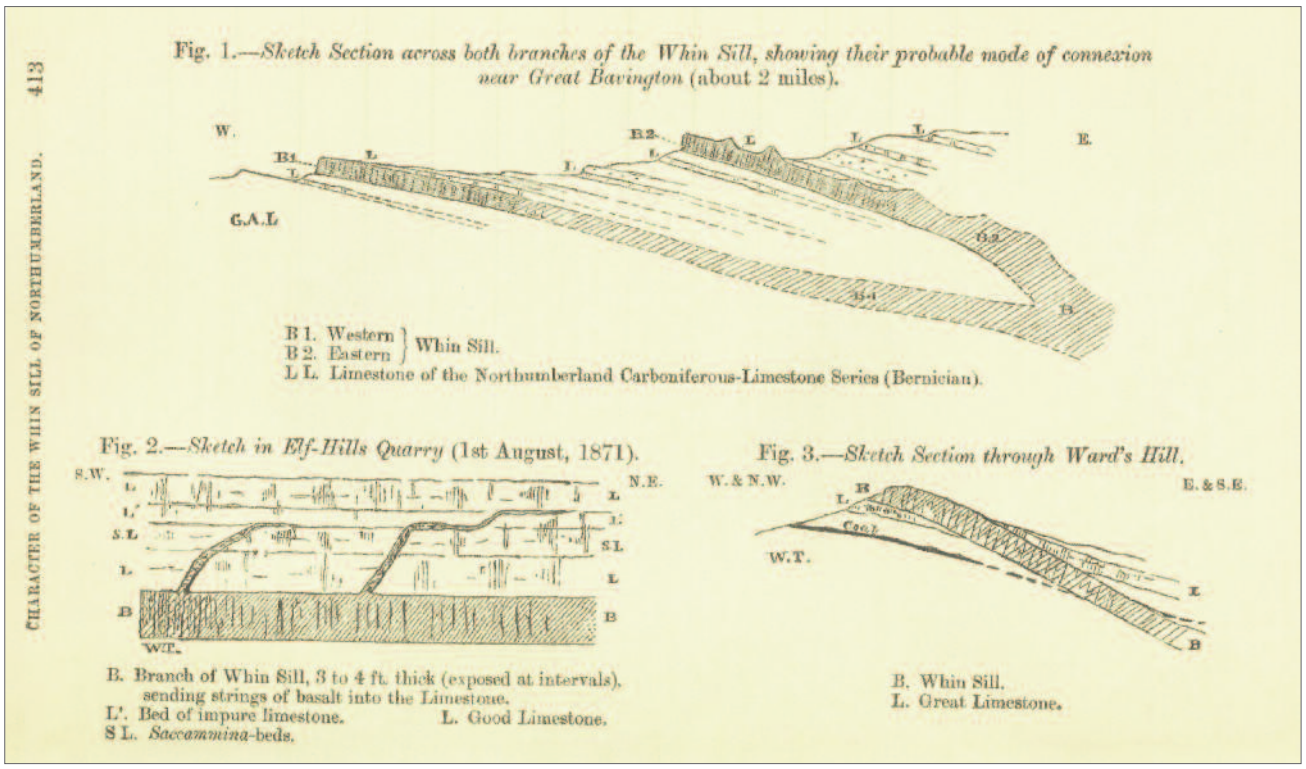

CHARACTER OF THE WHIN SILL OF NORTHUMBERLAND. 413
Fig. 1.—Sketch Section across both branches of the Whin Sill, showing their probable mode of connexion near Great Bavington (about 2 miles).
W.
E.
B1.
B2.
L
G.A.L
B 1. Western } Whin Sill.
B 2. Eastern }
L L. Limestone of the Northumberland Carboniferous-Limestone Series (Bernician).
Fig. 2.—Sketch in Elf-Hills Quarry (1st August, 1871).
S.W.
N.E.
L
L'
S.L
B
W.T.
B. Branch of Whin Sill, 3 to 4 ft. thick (exposed at intervals), sending strings of basalt into the Limestone.
L'. Bed of impure limestone.
L. Good Limestone.
S L. Saccammina-beds.
Fig. 3.—Sketch Section through Ward's Hill.
W. & N.W.
E. & S.E.
W.T.
B. Whin Sill.
L. Great Limestone.

Figure 23 Section sketch from 'On the intrusive character of the Whin Sill of Northumberland' (1877 Quart J Geol Soc ***33****) (Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

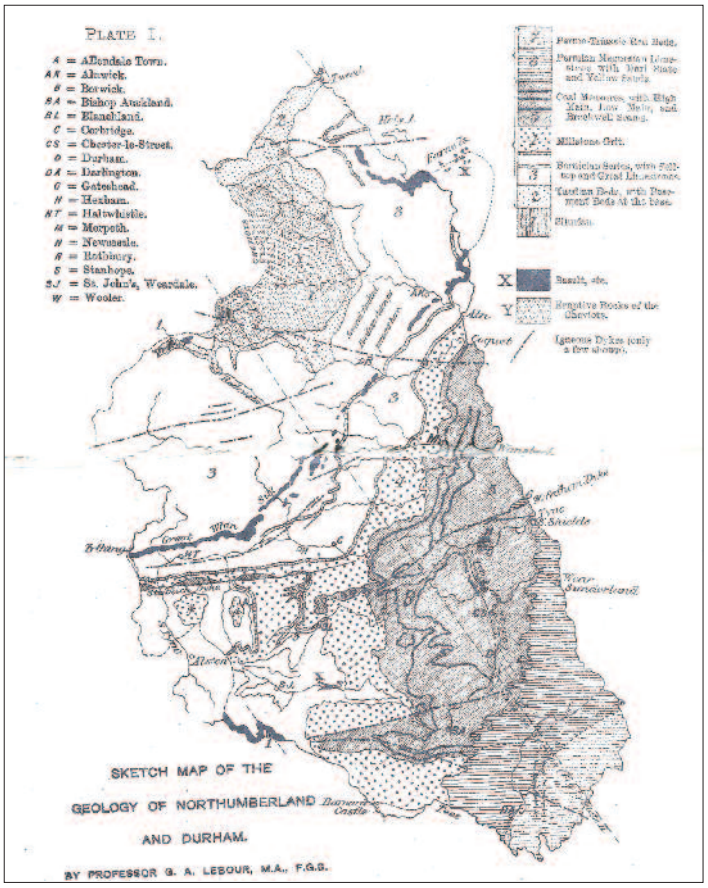
College) — David Page was the Professor of Geology at the college, but, due to illness, was in need of assistance. From the outset his workload exceeded that implied by his position and in 1879, on the death of Page, he became Professor of Geology, a position he held for the rest of his life.

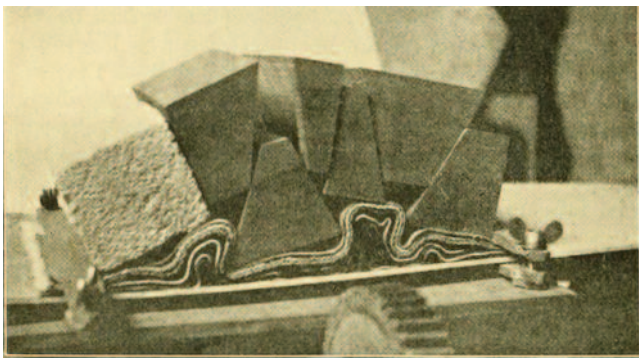
Lebour published more than 100 papers in many periodicals, mainly dealing with the Carboniferous System or with the geology of northern England, but spanning stratigraphy, palaeontology, physical, structural and applied geology, even including a paper on the distribution of goitre. He wrote the very useful *Outlines of the Geology of Northumberland* (1878), which appeared as a second edition in 1886, with the addition of Durham, and again in 1889 as an 'Official Local Guide' for the visit of the British Association to Newcastle upon Tyne in that year. He was also responsible for the geological section in the *Victoria County History of Durham* (1905) (Fig. 24).

Lebour was active in several committees of the British Association, including the committees on the Conductivity of Rocks and on Underground Temperatures. His interest on the transference of heat through the Earth's crust led him to measure underground temperatures in northern coal-pits and, along with Prof. A. S. Herschel, to determine the thermal conductivities of a variety of rocks. Their findings appeared in numerous reports from 1873 to 1881. Lebour's lectures treated geology from an historical aspect, often including personal anecdotes of the workers who laid the foundations of geology. He was renowned for being wonderfully fluent in both written and spoken word, and a born teacher. His students found him to be both genial and sympathetic, and his lectures often displayed a sense of humour, for he delighted in a good pun.

Primarily a field geologist, he believed the secrets of the Earth were to be gained by field study, with excursions to the Northumberland coast and to Appleby featuring prominently. The lecture room and laboratory were seen as necessary aids to the fieldwork. One of his contributions to teaching was a machine he designed in 1880 to demonstrate the process of fold formation and faulting in rocks. He also used Thomas Sopwith's models in his lectures (Fig. 25, *overleaf*).

Figure 24 Map from Handbook to the Geology and Natural History of Northumberland and Durham *(1889) (author scan).*





During his 39 years as Professor he helped develop Armstrong College from its small beginning to one of the largest and best equipped of the provincial colleges. In 1902 he was made Vice-Principal of Armstrong College and in 1904 became the first of my 'Northumbrian' geologists to be awarded the Murchison Medal (Fig. 26). Lebour was a founder of the Durham Philosophical Society and was always interested in natural history societies and field clubs, regretting that the amateur geologist had been largely displaced by the professional. One of his last papers was an appreciation of the work of amateur field clubs and a plea for co-operation between natural history societies and field clubs in investigating geological problems.

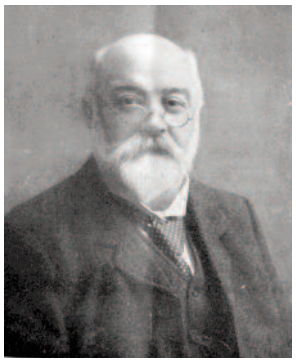


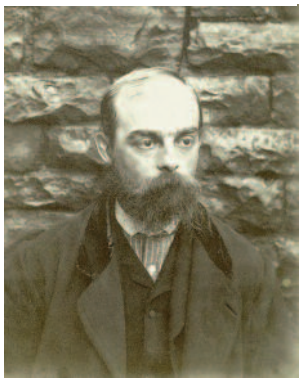
Figure 27 Prof. G. A. L. Lebour (reproduced from The Vasculum *(1918); not in copyright).*

In his later years Lebour suffered from a foot problem, which eventually requiring an operation that left him lame and unable to do fieldwork. His final illness lasted several months and he died at his home overlooking the Tyne at Radcliffe House, Corbridge on 7 February 1918 (Fig. 27).

Charles Thomas Clough (1852–1916)

Charles Clough was born in Huddersfield, Yorkshire on the 23 December 1852, the son of lawyer Thomas William Clough and Amelia Jane Ibeson (Fig. 28). He was baptized at the Queen Street Methodist Chapel on the 21 January 1853. Clough was schooled at Rugby from 1867 to 1871 before entering St John's College, Cambridge in October 1871. He was awarded an exhibition in Natural Science from 1872 to 1874 and obtained a First in the May 1873 examination. In 1874 he received First-class Honours in the Natural Science Tripos and was elected a scholar in 1874–5, taking his BA in 1875 and his MA in 1878.

Figure 28 Charles Thomas Clough (NERC BGS GeoScenic).



He had joined the Ordnance Geological Survey in March 1875, his first work was, like that of Gunn, was in northern England under H. H. Howell. His earliest fieldwork was in Teesdale, an area for which he had a lifelong affection, and resulted in his first paper, printed in the *Quarterly Journal of the Geological Society* in 1876, entitled 'The section at the

Figure 25 Labour's 'fold making apparatus' in action (Internet Archive http://archive.org — from Nature 60, 1899; reproduced non-profit, for educational purposes only).

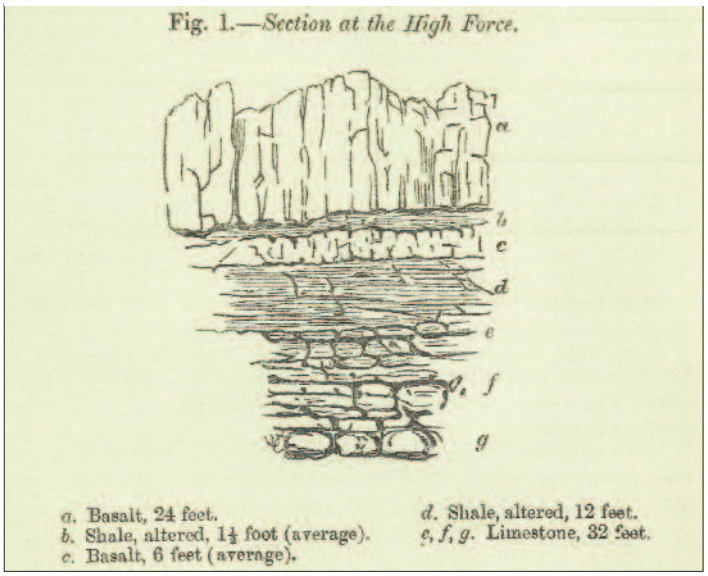
Figure 26 The Murchison Medal (Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).

High Force, Teesdale'. In it he corrected the succession, identifying two layers of basalt at the top (Fig. 29).

Clough spent eight years as a surveyor in Northumberland and Durham, living in Wooler for part of the time with his wife Anna, whom he married in Gateshead in 1881. He contributed to four memoirs for north Northumberland: *The Cheviot Hills (English Side)* (1888), in which the igneous succession of percolates, lavas, major and minor intrusions were recognised for the first time (Fig. 30, *opposite*); *Plashetts and Kielder* (1889), for which Clough was solely responsible; *Otterburn and Elsdon* (1887) by Hugh Miller Jnr, to which Clough contributed; and *Wooler and Coldstream* (1895), co-authored with William Gunn (*see above*).

As with Gunn, when the one-inch map for England and Wales was completed in 1884 Clough was sent up to Scotland to help with the survey there. Between 1884 and 1900 he surveyed the North West Highlands, Cowal, Loch Glencoul to Loch Inchard, Loch Maree, Glenelg, Skye and Soay. About 1900 he was transferred to Strathcarron, Eastern Ross-shire and, on the death of William Gunn in 1902, was promoted to District Geologist. Clough had already started the revision of the coalfields surveys, but also took charge of the work in northern Argyllshire and Mull. During this time he became less inclined to publish his papers in society transactions and journals, rather, publishing them as memoirs and maps.

Figure 29 Clough's section at High Force, Quart J Geol Soc *(1876) (author scan).*



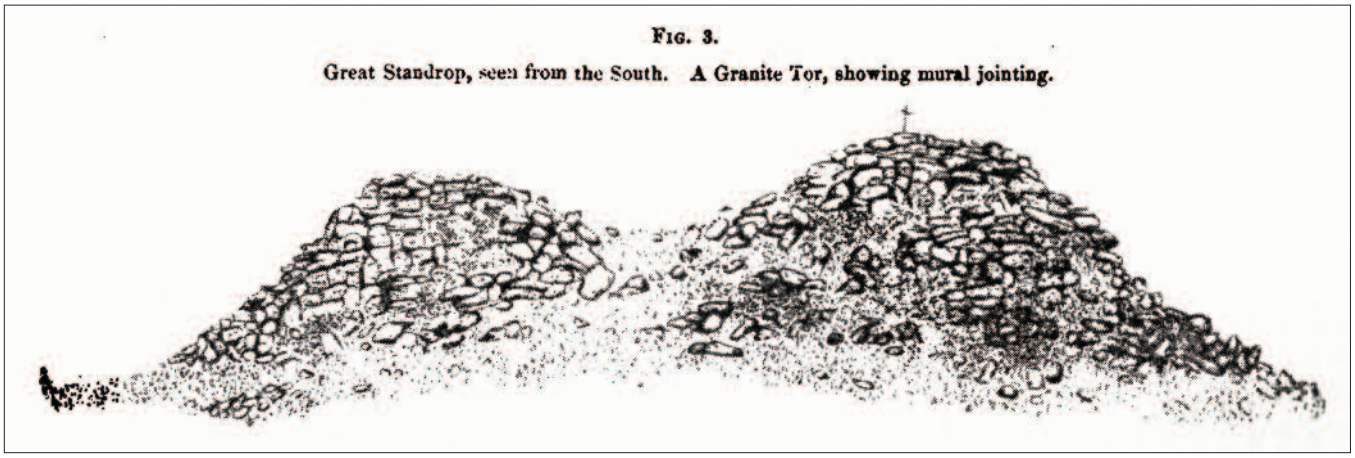


Figure 30 Sketch of Great Sandrop from Geology of the Cheviot Hills (English Side) *(1888) (author scan).*

Renowned for his powers of minute observation and diligence, Clough found fieldwork and map preparation far more rewarding than office work and memoir writing. Intricate geology was his forte, as shown by his detailed mapping of the North West Highlands on the six-inch scale. He was a simple man with a strong personality, perfectly content with rough food and life in a Highland shepherd's cottage. Kind-hearted and helpful, he treated others' opinions with respect (Fig. 31).

Clough was a Fellow of the Royal Society of Edinburgh, and of the Geological Society of London. He was awarded the Murchison Medal in 1906, was President of the Geological Society of Edinburgh from 1908 to 1910 and in July 1916 the University of St Andrews conferred on him the honorary degree of LL.D.

At the age of 63 Dr Clough was close to retiring, but consented to stay with the Geological Survey to help spread the workload brought on by the absence of junior survey members away on active service. In the course of fieldwork in the Bo'ness area, Clough had to cross a railway. At the time some mineral wagons were being shunted and Clough tried to pass in front of them, but, unfortunately, was run over and suffered compound fractures to both legs. He was given immediate attention and transferred by special train to Edinburgh Infirmary. The severity of his injuries required double amputation, but did not save his life. He died four days later on Sunday, 27 August 1916 from shock and acute hypostatic pneumonia. He was buried in Lasswade Churchyard on August 30th.

Figure 31 Horne, Peach and Clough in the field (NERC BGS GeoScenic)..

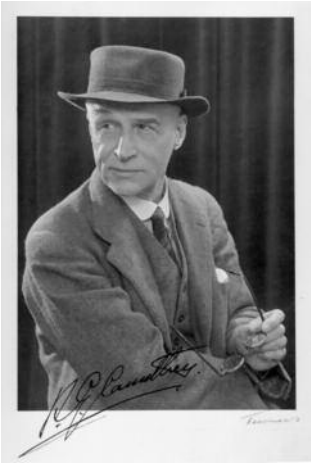
The Edinburgh Geological Society introduced two awards in recognition of Clough. The annual Clough Medal, the society's premier award introduced in 1935, and the biennial Clough Memorial Award in 1962 (Fig. 32).

Figure 32 The Clough Medal (reproduced with the kind permission of the Edinburgh Geological Society).

Robert George Carruthers (1880–1965)

Robert Carruthers was born on 29 September 1880 in Ashby-de-la-Zouch, Leicestershire (Fig. 33). He was the eldest son of Robert Johnston Carruthers, a draper, and his wife Maria Martha Paine. On leaving school he studied chemistry before joining Charles Lapworth's department at Birmingham University, but in 1903 he left there to join the Ordnance Geological Survey. Unlike Gunn, Lebour and Clough, Carruthers did not first work for the Geological Survey in northern England, but went straight to the Scottish Highlands to begin his career under B. N. Peach, who was now close to retirement. Carruthers played a considerable part in the detailed mapping of the Highlands during the end of what has been called the Peach-Horne-Clough era of Scottish geology.

Figure 33 Robert George Carruthers (NERC BGS GeoScenic).



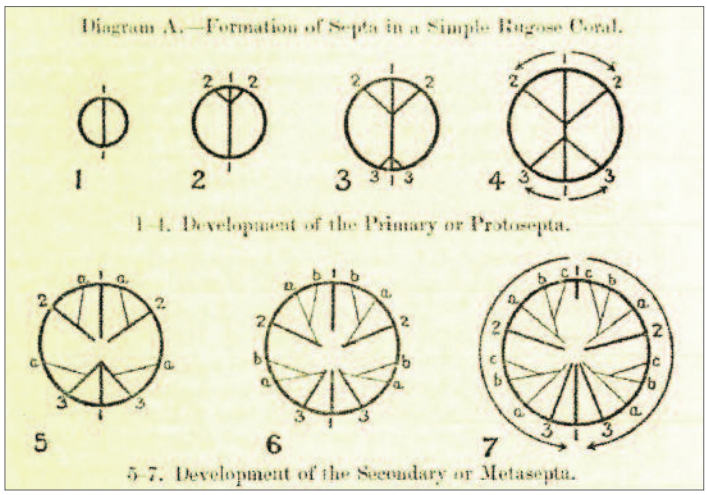


Figure 34 Septal Plan of the Rugosa*, from* Annals and Magazine of Natural History *Nov 1906 (Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

Because of the need to resurvey the Scottish coalfields, survey work was split into two seasons. In the summer months they surveyed the Highlands and during the rest of the year they mapped the coalfields. Carruthers' early years in this work brought him into contact with the Carboniferous corals and led to him writing several important papers on the morphology and zonal value of corals, including a well-known paper with original text figures of the primary septa in *Rugosa* (Fig. 34) and a famous study on *Zaphrentis*, said by Gertrude Lillian Elles and quoted in is obituary (1966 *J Geol Soc* **35** (pt 4, no. 18) as being "the most perfect little study in stratigraphical palaeontology that has yet been given to the geological world." Through these publications Carruthers developed an immense reputation as a palaeontologist, influencing the work of others for many years.

He also part-authored several Scottish Survey memoirs including the somewhat topical *Oil-Shales of the Lothians* (1912), as well as those covering Glasgow, Caithness and Corrour, and [the] *Moor of Rannoch*. His most memorable single contribution was probably interpreting the Ballachulish area. Carruthers ideas, put forward in 1913, were in opposition to E. B. Bailey's published views. It was not until 1929 that Bailey realised that he was wrong and Carruthers right, and subsequently credited him with having "successfully disentangled the true sequence" (Fig. 35).

World War I interrupted Carruthers' career when he signed up for Short Service on 27 April 1916, joining the Heavy Section Machine Gun Corps. He was posted to France, where he rose to the rank of Corporal in the Tank Corps and was a draughtsman. While in service in 1917 he was awarded the Bigsby Medal by the Geological Society of London (Fig. 36). He was demobilized on 10 January 1919 and was subsequently awarded the Victory and British Medals on 28 June 1921. Carruthers declined his military awards, however, and the medals were scrapped.

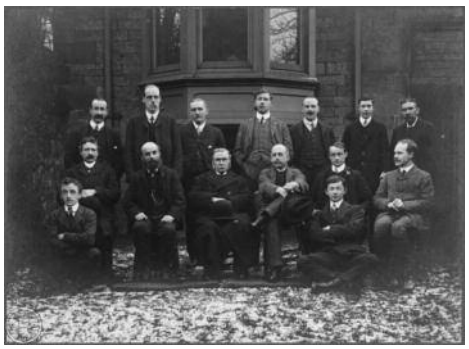


Figure 35 Members of the Scottish Survey, showing R. G. Carruthers (middle standing) and C. T. Clough (seated second left) (NERC BGS GeoScenic).

AWARDED BY THE GEOLOGICAL SOCIETY OF LONDON
FOR WORK OF GREAT MERIT
FOUND
J. J. BIGSBY M.D. F.R.S.
SILURIAN PRIZE MEDAL FOUNDED 1875

Figure 36 The Bigsby Medal (Internet Archive http:// archive.org; reproduced non-profit, for educational purposes only).

Shortly after returning from the war he moved from Edinburgh to take up the position of District Geologist in charge of the newly created Northumberland and Durham District. He was to remain here for the rest of his service and was responsible for revision of the one-inch sheets in north-eastern England, including their memoirs. Eight sheets and five memoirs were published by his retirement, including those entitled *Belford, Holy Island and the Farne Islands* (2nd edn; 1927), *Geology of the Alnwick District* (1930; Fig. 37, *opposite*), and the *Cheviot Hills* (1932). In addition he contributed special reports on the mineral resources of Great Britain for the Geological Survey. These covered lead, zinc, fluorite, baryte and witherite associated with the North Pennine orefield.

Carruthers developed an interest in Pleistocene geology following his move south. Detailed study of the drifts in Northumberland and Durham led him to conclusions that formed the basis of his 'Undermelt Theory'. In it he favours the idea that only one glacial period in Britain was required to produce the deposits. He was vociferous in the presentation of his provocative ideas. A paper read at the Geological Society of London in 1939 on Northern Glacial Drifts created such a discussion that an extra meeting had to be arranged to debate it. In two presidential addresses to the Yorkshire Geological Society in 1943 and 1944 he was still providing evidence; and he went on to publish a private paper in 1953. [Carruthers' papers include: 'On northern glacial drifts: some peculiarities and their significance' (1939 *Quart J Geol Soc* **95**); 'On northern glacial drifts: some peculiarities and their significance' (1939 *Quart J Geol Soc* **96**); 'The secret of the glacial drifts' (Presidential Address Nov. 1943; published 1947 *Proc Yorks Geol Soc* **27**); 'The secret of the glacial drifts. part II: applications to Yorkshire' (Presidential Address Dec. 1944; published 1948 *Proc Yorks Geol Soc* **27**); and 'Glacial drifts and the Undermelt Theory'. R. G. Cacrruthers 1953]. *[K. E-E. and Ed. — see also:* M. R. Bennett and P. Doyle 1994 'Carruthers and the theory of glacial undermelt: lessons from a pamphleteer?' (*Geology Today* **10** (5), 191–4); and on the 19th-century debates about the nature of the ices age(s) in Britain see A. O'Connor 2008 'Nineteenth-century battles over bones and ice: Geikie versus Dawkins' (*OUGSJ* **29** (2), 66–9).]

Some of Carruthers' conclusions were not valid, but most of his views are now generally accepted and he did generate a more critical examination of glacial deposits than had taken place up to that time.

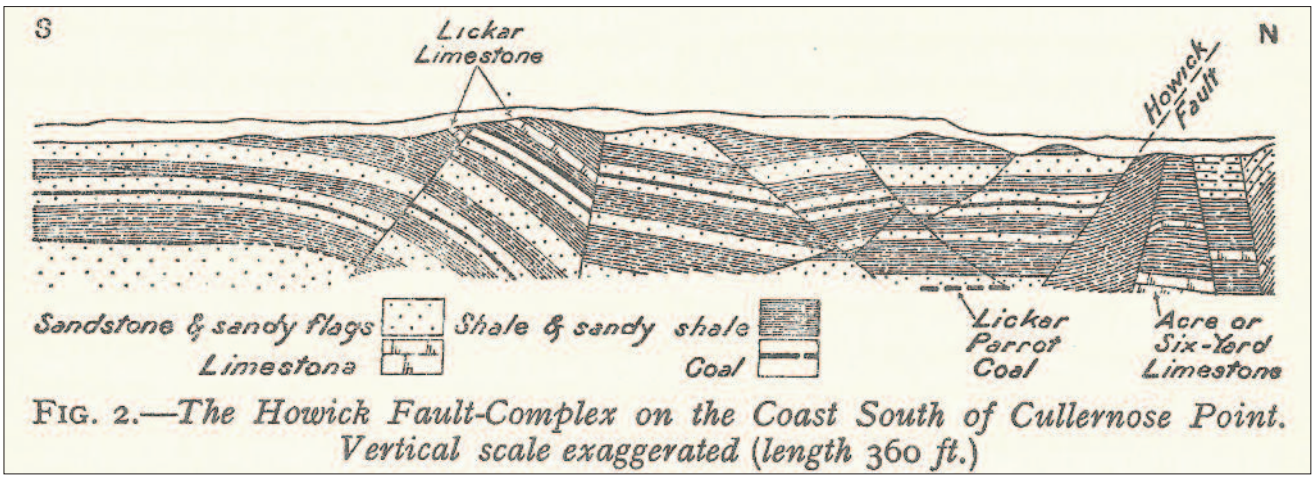
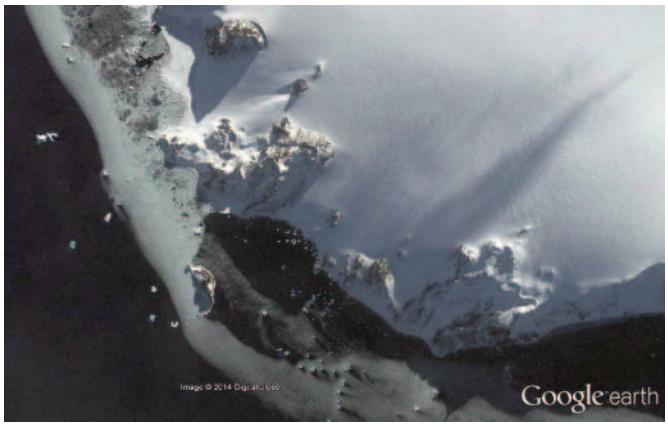


Figure 37 Section drawing of the Howick fault complex, from Geology of the Alnwick District *(1930) (author scan).*

Carruthers was an inspiring leader, well liked by his staff at the Newcastle office. One of his colleagues said of him: "R. G. C. never once let us down. I trust none of us ever let him down." He died, unmarried, at his home in Stocksfield, Northumberland on 24 March 1965.

Fossilised wood and leaf remains were found in February 1996 near the base of a sub-vertical rock cliff overlooking Geologist's Cove at the entrance to Admiralty Bay, King George Island in the South Shetland Islands. In 1999 it was decided to name the cliff 'Carruthers Cliff' after R. G., with nearby areas also named after Quaternary geologists. Appropriately, over 90% of the island is permanently glaciated (Fig. 38).

Figure 38 Carruthers Cliff , King George Island, South Shetland Islands (62˚11'S 58˚17'W) (from Google Earth; reproduced non-profit, for educational purposes only).



David Woolacott (1872–1924)

David Woolacott was born in Sunderland on 1 July 1872 (Fig. 39). He was the son of James Woolacott, a gardener from Paignton, Devon, and Jane Moffat Anderson of Muirkirk, Ayrshire, who were married in Stockton in 1866. Sadly, his father died when Woolacott was only a year old and it was his mother who exercised considerable influence on his early leanings towards educational pursuits.

*Figure 39 David Woolacott (*The Vasculum*, 1924) (author scan).*

He entered Armstrong College in 1891 as a student in the Day Training Department, where he studied geology under Prof. Lebour, graduating in 1895 with a Distinction in Geology. On leaving the college, Woolacott was appointed Science Master at the Valley Road School in Sunderland. He continued his geological studies in his spare time, doing much to stimulate interest in geology by writing general accounts of the local geology, including a series of articles in *The Sunderland Weekly Echo* entitled 'The Rocks Around Us' (1896). These articles were published as a book in 1897, entitled *The Geology of North-East Durham* and dedicated to G. A. Lebour (Fig. 40). That same year he was elected a Fellow of the Geological Society of London.

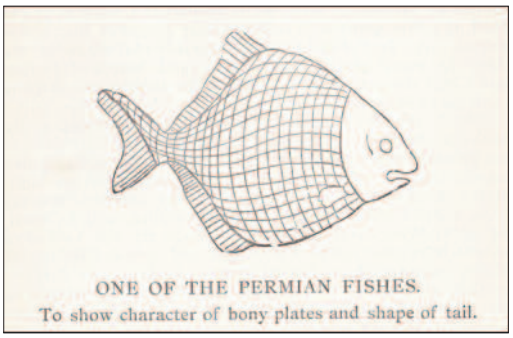


Figure 40 Sketch from The Geology of North-East Durham *(1897) (author scan).*

In 1899, when Lebour was unable to carry out fieldwork because of his foot injury, Woolacott was appointed Demonstrator in Geology at Armstrong College. This required him to conduct fieldwork on Saturdays and during the Easter holidays. Although he travelled widely in pursuit of geological knowledge, visiting many European countries as well as Canada and Jamaica, his original work was almost completely on geological problems in Northumberland and Durham. His earliest observations were on the Pleistocene deposits and underlying Permian rocks of the region, particularly the raised beaches and boulder clay of East Durham and the section at Claxheugh. This work appeared in the publications of local natural history societies and it was his work on glacial geology that led to his award of a DSc in 1904.

Woolacott was transferred to the full-time teaching staff at Armstrong College in 1905, where he remained for the rest of his career, rising to Lecturer and finally to Reader in Geology. Using data from the numerous boreholes and sinkholes made in search

*Figure 41 Map from 'Pre-glacial valleys' (*Quart J Geol Soc *1905) (Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

of coal, Woolacott undertook the laborious task of mapping and collating the information, which enabled him to determine the contour of the pre-glacial surface of the area, identifying the courses of the Tyne, Wear and Wansbeck rivers as they existed before the coming of the ice. The main results were collected into his paper 'Superficial deposits and pre-glacial valleys of the Northumberland and Durham Coalfield' (*Quart J Geol Soc* 1905) (Fig. 41).

Some of Woolacott's best known work was on the Permian of the Sunderland region. He revised the classification of the Permian rocks, studying the significant effect tectonics had played in production of the structural features of the Magnesian Limestone. From 1919 he was a regular contributor of papers to the *Geological Magazine*, contributing papers on the Carboniferous, Permian and Pleistocene geology of north-east England; one notable paper was 'On the 60-ft. raised beach at Easington, Co. Durham' (*Geol Mag* 59 1922), which he had discovered in 1912, accompanied by C. T. Trechmann, while leading students on a fieldtrip (Figs 42 and 43).

David Woolacott was awarded the Murchison Fund by the Geological Society of London in 1920 in recognition of more than 20 years of geological work. He never married, and lived in Sunderland all his life with his mother and elder sister, latterly at 8 The Oaks West. His mother passed away in 1921. In 1923 Woolacott underwent surgery for an internal complaint, with apparent success; but unfortunately the same trouble returned while he was on holiday in Oxfordshire, on this occasion being inoperable, and he died at Headington on 4 August, 1924.

Woolacott had a cheerful disposition and was well liked both by colleagues and students, and had a wide circle of acquaintances. His untimely death prevented the completion of a series of papers he had planned to present as a complete account of the local geology. The Permian brachiopod *Chonetes woolacotti* is named after him.

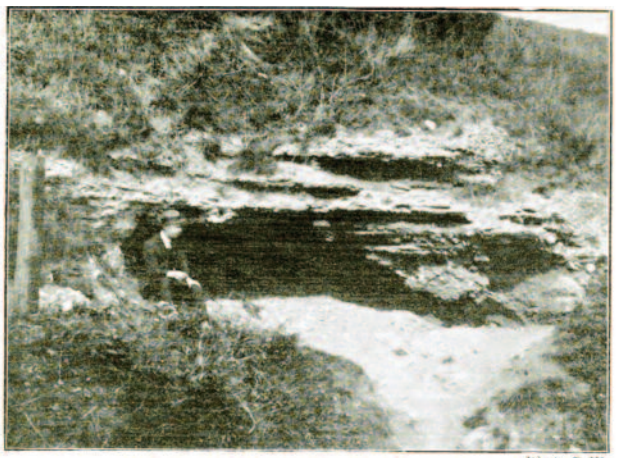


FIG. 1.—60 ft. Raised Beach at Easington. Photo D. W.

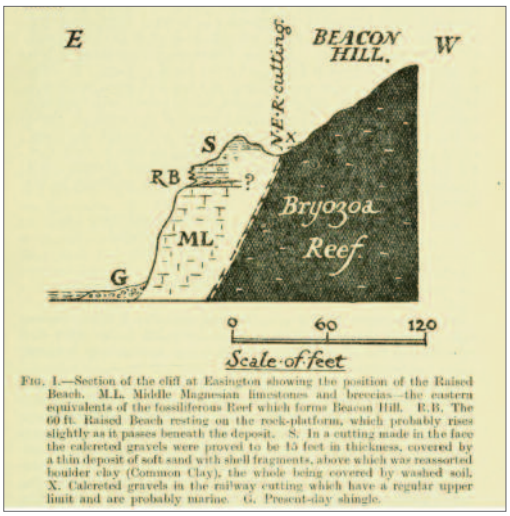


FIG. 1.—Section of the cliff at Easington showing the position of the Raised Beach. M.L. Middle Magnesian limestones and breccias—the eastern equivalents of the fossiliferous Reef which forms Beacon Hill. R.B. The 60 ft. Raised Beach resting on the rock-platform, which probably rises slightly as it passes beneath the deposit. S. In a cutting made in the face the calcreted gravels were proved to be 15 feet in thickness, covered by a thin deposit of soft sand with shell fragments, above which was reassorted boulder clay (Common Clay), the whole being covered by washed soil. X. Calcreted gravels in the railway cutting which have a regular upper limit and are probably marine. G. Present-day shingle.

Figure 42 Easington Raised Beach, from Geological Magazine *(1922).*
Figure 43 Sketch of Easington Raised Beach in Geological Magazine *(1922). (Both images: Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

Charles Taylor Trechmann (1884–1964)

Charles Trechmann was born at 10 Cliff Terrace, Hartlepool on 28 of June 1884 (Fig. 44). He was the son of Hartlepool cement manufacturer and works owner Charles Otto Trechmann, and Gertrude Elizabeth Taylor of Bedlington. Charles Otto's father, Peter Otto Eduard Trechmann, was a German immigrant who came to north-east England in 1843 and soon established a shipping agency at Hartlepool (Trechmann Bros. — later Trechmann SS Co.). In 1848 he took over a 'Roman Cement' manufacturing plant in Hartlepool, which became Otto Trechmann Ltd (later Warren Cement Works) and switched to manufacturing Portland cement, initially using Thames chalk and later limestone from Purfleet Quarry. He became a naturalised British Citizen in 1849, died in 1892 and left more than £95,000 in his will.

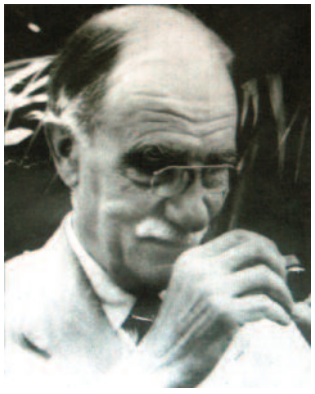


Figure 44 Charles Taylor Trechmann (© West Indies Museum of Geology).

Charles Otto Trechmann had obtained a PhD in Chemistry from Heidelberg University before taking over management of his father Peter

Otto's cement works. While at university he acquired an interest in mineralogy and crystallography and began building a large collection. In 1892 he acquired Hudworth Tower in Castle Eden, which then became the family home. In 1905 the mineral trechmannite was named in his honour.

It is hardly surprising, given this background, that the young Charles Taylor Trechmann, on leaving Tonbridge School in Kent should progress to Armstrong College to study geology and chemistry. After his graduation he went on to study at Basle and Paris before returning to Castle Eden to work as an analytical chemist at his father's cement works. Conveniently, this allowed him plenty of time to study the chemistry and stratigraphy of the Magnesian Limestone. He had been fascinated by the formations since his childhood picnics at Blackhalls Rocks. Papers he wrote on the different reef palaeoenvironments of the Zechstein outcrops of south-east Durham in 1913 and 1914 provide some of the most detailed information on the area. As a result of this work he became a Fellow of the Geological Society of London and was awarded the degree of Doctor of Science by Durham University. He went on to publish papers on north-east Permian geology in several journals.

In 1914 the impending threat of war reportedly caused the Trechmann family to hide their German origins by suggesting they were actually of Danish descent. Any question of family loyalty to Britain was quashed, however, following investigations into an incident in the Mediterranean in 1914. One of the Trechmann Steamship Company's ships, the *SS Wilster* (named after Peter Otto's home town in Germany) was thought to have supplied coal to the *SMS Goeben*, a German battle cruiser, while in port in Messina, enabling it to evade the pursuing British battle cruisers. The Admiralty investigated the Trechmann family and found them to be a respectable family, long established in England and cleared them of any involvement. Indeed the shipping company provided many of its fleet for the war effort and suffered huge losses, including the *SS Hudworth*, built in 1916 and sunk by German submarine *U-35* on 6 January 1917 near Malta. In fact, almost all the Trechmann fleet was lost in World War I and their shipping business was wound up in 1919.

Having a shipping company in the family had its perks. Charles travelled widely and, at the age of 25 on a first-class ticket, he visited Jamaica, a country he would visit many times in the future. During the World War I, he made several voyages to New Zealand, where he visited many Triassic localities, collected fossils (including many type specimens) and examined collections. His work helped sort out the Permo-Triassic stratigraphic controversies in the Nelson area and there is even a formation within the Otamitan Stage (Triassic) of New Zealand named after him — the Trechmann Concretionary Siltstone.

His father died in June 1917 leaving £102,000 in his will and bequeathing much of his mineral collection to the British Museum, the remainder going to Charles Jnr. He also inherited the family home and took over the management of the cement works while continuing his geological pursuits. He drilled several boreholes in the Hartlepool Headland area, establishing the presence and thickness of the Hartlepool Anhydrite. The plant was sold to ICI in the mid 1920s, which subsequently mined the anhydrite. Trechmann's work also formed the basis for the development of the anhydrite mine at Billingham.

Being of independent means allowed Charles to pursue his geology and archaeology (his other great interest) at leisure (Fig. 45). After the war he travelled to Europe (with Woolacott in 1922), Africa, South America and, particularly, the Caribbean. He adopted a research programme through the 1920s and 1930s that

Figure 45 Trechmann (back row, far right) on GA excursion to Shropshire, 1925 (digitised from the Geologists' Association Carreck Archive, reproduced with permission of the British Geological Survey).

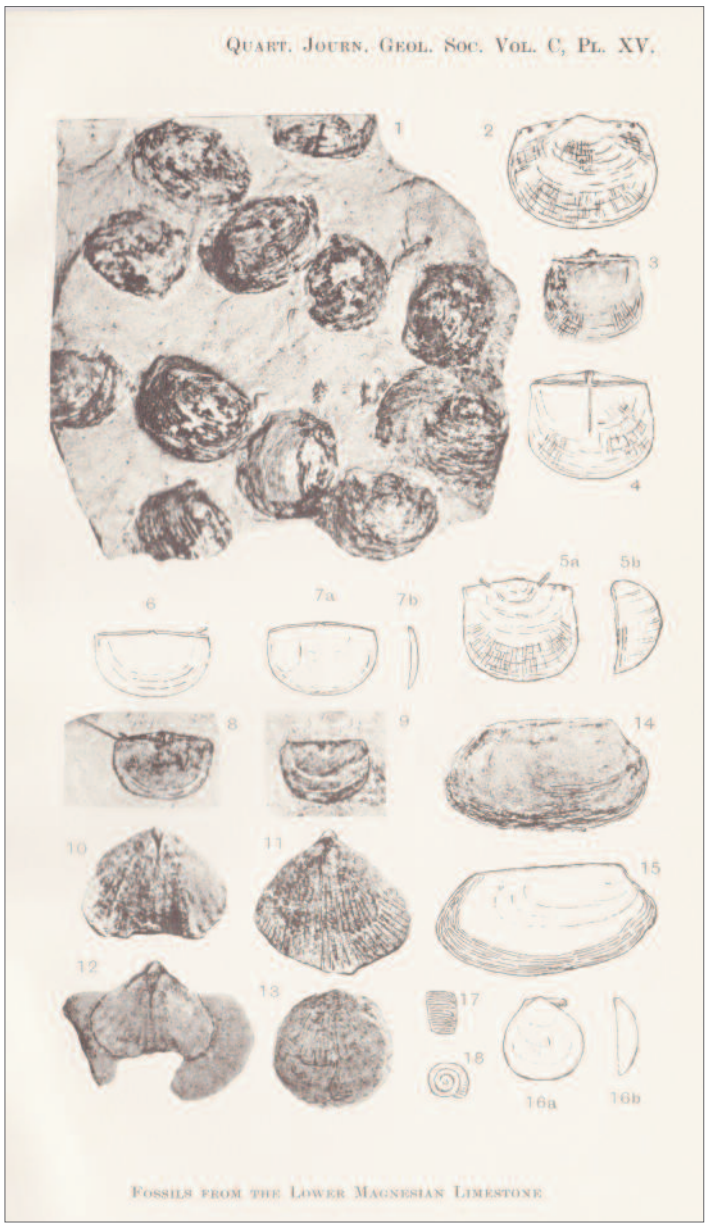


*Figure 46 Page of fossil sketches from Trechmann's 'On some new Permian fossils from the Magnesian Limestone near Sunderland' (*Quart J Geol Soc *1945) (top of page:* Chonetes woolacotti *from Ford Quarry) (author scan).*

involved working on the archaeology and geology of north-east England in the summer months until September, overwintering in the Antilles before returning to Castle Eden in May. His contribution to the geology of the Caribbean was considerable, producing more than 40 monographs on the subject, including the first detailed geological descriptions of many of the islands — for example Jamaica, Barbados, Tobago and Carriacou. His studies of fossil molluscs include seven papers on the Cretaceous and Caenozoic fauna of Jamaica, published in the *Geological Magazine* between 1922 and 1930; his observations remain standard references for many areas and stratigraphic units, although opinion on his abilities as a stratigrapher and petrologist have been questioned.

World War II interfered with his travelling, so he concentrated on local geology, but he was quick to resume his transatlantic voyages when peacetime returned. Back in County Durham in the months of May and June, Trechmann would lead the student field club on excursions to the Permian of the Durham coast (Figs 46 and 47) and elsewhere. He was a true 'gentleman geologist' with associated eccentricities. Students nicknamed him 'The Laird of Castle Eden Dene', as he would arrive by chauffeur-driven saloon and preferred a stick or furled umbrella to a hammer. He would dress in grey tweed with a Homburg hat and gold-rimmed spectacles attached to his lapel by a black ribbon. Not averse to sharing his riches, on one occasion he took a party to explore the Hartlepool Dolomite north of Seaham Harbour. At lunch time he proceeded to a precise point on the beach where he uncovered a cache of bottled beer, which his chauffeur had buried previously.

He was also interested in the Quaternary deposits of east Durham and published a series of papers between 1915 and 1952 on the subject. His most significant contribution in this field was his discovery of the Scandinavian Drift near Horden. Trechmann made detailed records and collected many specimens, which have been of much use to later workers. He was happy to present specimens to local and national museums, but also had a large personal collection of both local and worldwide specimens, which he kept in his greenhouse. He took great pleasure in showing visiting geologists the carefully labelled specimens, as well as the magnificent vine that grew alongside them.

His archeological interests were wide ranging. He wrote several articles on Neolithic and Mesolithic finds from the Durham region and also acquired many small antiquities, particularly Egyptian, from auctions and dealers. One of his most significant finds was a statue of Ramesses IX, Neferkare, which he bought from the Lowther Castle sale in 1947. It is now in the Edinburgh Museum, being one of more than 400 pieces bequeathed to the museum by Trechmann. At the time of the sale it had been used as a support for a tree branch in a case of stuffed birds!

In 1949 he returned to New Zealand for the Pacific Sciences Congress at Christchurch, more than 30 years after his last visit to the country. There he met geologist Harold Wellman, whose discovery of the 'Alpine Fault' in South Island was presented at the Congress. They got on well, both men delighting in undermining established dogma. One night at dinner in the Black and White Hotel, Westport, Wellman produced a rock sample collected from near the base of the Ohika Formation. He was unsure whether it was igneous or sedimentary and handed it to his colleagues — petrology Professor C. E. Tilley from Cambridge and John Reed, an NZGS petrologist. Tilley said it would need a thin section to be able to identify it and Reed agreed. Trechmann asked to have a look, left the group for a short while, then returned announcing it to be sedimentary (as Wellman had thought). Tilley asked how he could be sure.

Figure 47 Trechmann exploring the Hartlepool Submerged Forest, Hartlepool Headland in background (untraced Web source).

Figure 48 Trechmann in the Waipara Gorge, Canterbury, examining the fossil Waiparaconus*, 1944 (Geni.com).*

"You see", replied Trechmann, "I always carry a small carborundum stone and a lens with me. I smooth a bit of the rock and spit on it, and then use the lens. But you couldn't do it, Tilley; it's the spit that counts!" (Fig. 48).

In his later years Trechmann's unorthodox approach to geology often proved controversial. Jamaican Survey geologist C. A. Matley had recognised a Basal Complex under Jamaica and the Caribbean. He noticed similarities to the Mona Complex, which he had mapped in Anglesey and the Lleyn Peninsula in the 1920s, and saw analogous structural relationships in the Caribbean. His theory proposed that the Antillean Islands were the peaks of a foundered continent. In response to this Trechmann changed his research from stratigraphy and mollusca to tectonics. He formulated his Theory of Mountain Uplift in competition with Matley's Basal Complex. Trechmann's theory suggested that mountain uplift was a consequence of lunar attraction, supported by pressure from deep columns of ocean water, which induced metamorphic changes at shallow crustal depths. Lacking peer support for his theory, Trechmann had to publish it privately (in four monographs between 1942 and 1955). Matley died after the first volume appeared and the theory was largely ignored by professional geologists. Trechmann was clearly unimpressed by the response to his theory, the final volume of his series being entitled *The British Association for the Suppression of Science or, A New Explanation of Mountain Uplift based on Lunar Gravitation and Oceanic Pressure*. This was an extension of a paper submitted to the British Association for Advancement of Science (BAAS) meeting in Liverpool in 1953 and, according to the Introduction, the paper was refused publication in the *BAAS Proceedings*.

In terms of modern plate tectonics Trechmann's theory is remembered for its errors and has been described as being not just wrong, but "wrong at the wrong time".

A lifetime of research and publication was not overshadowed by his Uplift Theory, however, and in 1956 he received the R. H. Worth Prize awarded by the Geological Society of London to those who make distinguished contributions to geology as amateurs. Trechmann was also a philanthropist, donating many specimens to the British Museum, and giving financial assistance for the purchase of dinosaur skeletons and the Bronze Age(?) Galley Hill Man. He also purchased the painting *Discussion of the Piltdown Skull* by John Cooke, R.A., for the Geological Society of London.

Trechmann died in Barbados at the Diagnostic Clinic, Beckles Road, St Michael, on 18 February 1964, aged 79, following injuries sustained during fieldwork. In his will he left £136,000 and offered his specimens, articles and library to the British Museum, requesting that anything they did not require should be offered to the Sunderland Museum, where much of his collection is still housed. Two genera bear his name; *Trechmannia*, a Carboniferous gastropod from Weardale, and *Trechmannella*, a large Iranian rudist.

Arthur Holmes (1890–1965)

Figure 49 Arthur Holmes (Wikipedia, Public Domain).

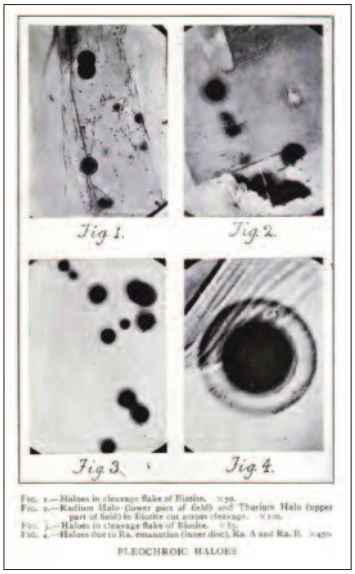
Arthur Holmes was born in Hebburn, Gateshead on 14 January 1890 (Fig. 49). He was the son of cabinet-maker David Holmes and his wife, schoolteacher Emily Dickinson, both of Newcastle. After a short period of living in Elswick, Newcastle, the family moved back to Gateshead and Arthur spent most of his childhood living in Low Fell (Fig. 50). He attended Gateshead Higher Grade School (later Gateshead Grammar School) where, at age 15, he gained First-class honours in the School Certificate examinations. In the Sixth Form his Science Master, Mr James McIntosh, introduced him to the *Popular Lectures and Addresses* of Lord Kelvin, as well as to the recently translated work of Swiss geologist Edward Suess, *The Face of the Earth*. These books influenced the direction his life was to take and instigated Holmes' interest in geochronology. At this time there was no numerical geological time scale and the 'Age of the Earth' controversy was at its peak. In 1897 Kelvin had calculated an age of about 20 million years, while most geologists believed at least 100 million years would be necessary, and religious groups required only 6,000 years. Holmes recalled seeing, written in the family Bible, the date of creation as being 4004 BC. He was puzzled by the odd '4' and later wrote, "Why not a nice round 4,000 years? And why such a recent date? And how could anyone know?"

At age 17 Holmes was awarded a scholarship (£60 per year) to study physics and mathematics at the Royal College of Science in London (now Imperial College). In his second year he took a course in geology and, against the advice of his physics tutors, chose to follow this path. Radioactivity had been discovered in 1896 and by 1904 Ernest Rutherford had used the decay process to determine the first radiometric date. Holmes spent much time in the laboratory of Robert Strutt, the Professor of Physics at Imperial. Strutt had done much work on the estimation of the age of minerals and rocks by measuring their radium and helium content. A problem with this method was leakage of helium, which permitted only a minimum date to be established. Work by Bertram Boltwood, another researcher, indicated that lead was the final decay product for uranium, and Holmes used this information to develop an alternative technique and subsequently performed the first uranium–lead analysis specifically for age-dating purposes, while still an undergraduate. The result was a date of 370Ma for a thorite-bearing nepheline-syenite Devonian rock from Brevik near Oslo, Norway!

Gateshead Metropolitan Borough Council
ARTHUR HOLMES
(1890 - 1965)
One of the most important geoscientists of the 20th century and author of 'Principles of Physical Geology'.
He lived here in his early years and attended Gateshead Secondary School.
2005

Figure 50 Gateshead Metropolitan Borough Council's honorary blue plaque to Holmes at 19 Primrose Hill, Low Fell (2005) (Wikimedia, Creative Commons).

Holmes graduated with a BSc in Physics in 1909 and became an



Associate of the Royal College of Science the following year, receiving a second degree, in geology, in 1910. He was forced to leave his studies, however, in search of a much-needed income and obtained a job prospecting for minerals in Mozambique for Memba Minerals, a mining company. He learned the techniques of fieldwork and began studying Precambrian metamorphic rocks and Tertiary lavas. In April 1911, while still in Mozambique, his paper on age-dating was read to members of the Royal Society. Unfortunately, after six months abroad, during which time no significant discoveries had been made, Holmes contracted malaria. He became so ill that a notice of his death was telegraphed home. Fortunately, he recovered and caught the first boat back to England, arriving in November 1911. What he did gain from his trip to Africa was an interest in petrogenesis, another field to feature strongly in his future studies.

In 1912 he graduated with a PhD, became a Fellow of the Geological Society and was appointed Demonstrator in Petrology at Imperial College, a post he held until 1920. He began writing to geologists such as Alex du Toit and Johannes Sederholm, asking for samples on which to develop his dating technique. He had become the world authority in the infant science of geochronology. His research subsequently led to the publication of the first edition of *The Age of the Earth* in 1913, in which he estimated an age of up to 1,600Ma for the Archean system (Fig. 51). At the same time his system for dating hit a snag. The discovery of isotopes in 1913 slowed progress, as it was difficult to chemically determine the different isotopes of lead, significantly increasing the time taken to obtain results.

Just before the outbreak of World War I, Holmes married Gateshead-born Margaret Howe in their home town. Throughout the war he remained a Demonstrator at Imperial College, publishing several articles on radioactivity and its use in dating geological time. Some of these were co-authored by his best friend at school and fellow scientist, Robert Lawson. He found himself having to defend his findings in the face of opposition from established geologists, who believed that a date of 100Ma was correct. At a talk given at the Geological Society of London in 1915 he recalled:

> I was being violently attacked by the reader of a paper who insisted the Age of the Earth must be less than 100 million years old. In the discussion that followed I had occasion to refer to the isotopes of lead, then newly discovered. But isotopes did not seem to have been heard of in that audience. The reader of the paper insisted that all atoms of lead must have the same atomic weight, and I found myself in an exasperated minority of one.

In 1917 he was awarded a Doctorate of Science by Imperial and towards the end of the following year his first son, Norman, was born. Working in his teaching laboratory in South Kensington he produced a large amount of data, which he went on to publish in two books: *The Nomenclature of Petrology* (1920) and *Petrographic Methods and Calculations* (1921). Towards the end of the war his research activities were curtailed as he was required to carry out work for the government for the war effort, namely finding new sources of potash, most of which had previously come from Germany.

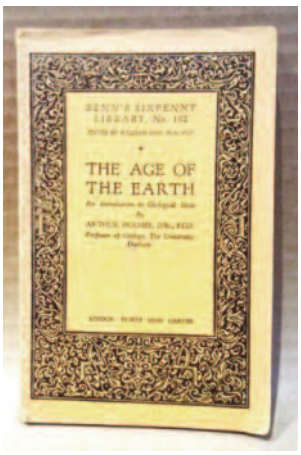


Figure 51 Frontispiece from The Age of the Earth *(1913) (Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

*Figure 52 Benn's 1927 'Sixpenny Library' edition of T*he Age of the Earth *(Worthpoint, Limited Use License).*

After nine years as a Demonstrator, Holmes was still only earning £200 a year, not enough to support his young family, so in 1920 he once again left Imperial College, this time as Chief Geologist with Yomah Oil Ltd, an oil company in Burma. His new salary was some £1,400 per year, but the move to Burma proved no more successful than his time in Mozambique. The job lasted only two years as a result of the company failing to pay its employees. Tragedy struck the family before their return to England when Norman died from dysentery. Holmes arrived bankrupt, jobless and devastated by his son's death. Back in their native north-east England Holmes and his wife scraped a living doing what they could. He gave piano recitals and opened a shop in Newcastle with his wife's cousin, selling Asian crafts and furs.

In 1924 things started to look up for the Holmes family. Their second son, Geoffrey, was born and, around the same time, Durham University opened up a new geology department. In June 1924 they offered Holmes the post of Reader and then Professor of Geology, where he single-handedly formed the new department. He continued to publish profusely in academic papers, and with articles in magazines and newspapers, opening his work up to a wider audience. It earned him a reputation as "one of the few English geologists with ideas on a grand scale." He even produced an abridged paperback version of his *The Age of the Earth* as part of 'Benn's Sixpenny Library' series (1927) (Fig. 52).

While in Burma, Holmes had missed two important meetings of the BAAS. The first, in Edinburgh in 1921, discussed the age of the Earth with most of the speakers referring to Holmes' work on the subject. The general consensus was that radiometric methods produced a date of the right order of magnitude, agreeing that an age of around 1,600 Ma was correct.

The second meeting took place in Hull in August 1922. One of the topics to be discussed was advertised in *Nature* the week before as: "A discussion on Alfred Wegener's hypothesis of continental drift, in which both the geological and astronomical sides will receive attention." Wegener had first published his theory in Germany in 1912, although an English translation did not appear until 1924. Holmes visited Germany in 1912 and is likely to have heard the theory being discussed among geologists. At the Hull meeting the majority of speakers tentatively supported the theory, or at least thought it worthy of further investigation, although there was much opposition to it. Arthur Holmes had long been interested in the thermal history of the Earth and the

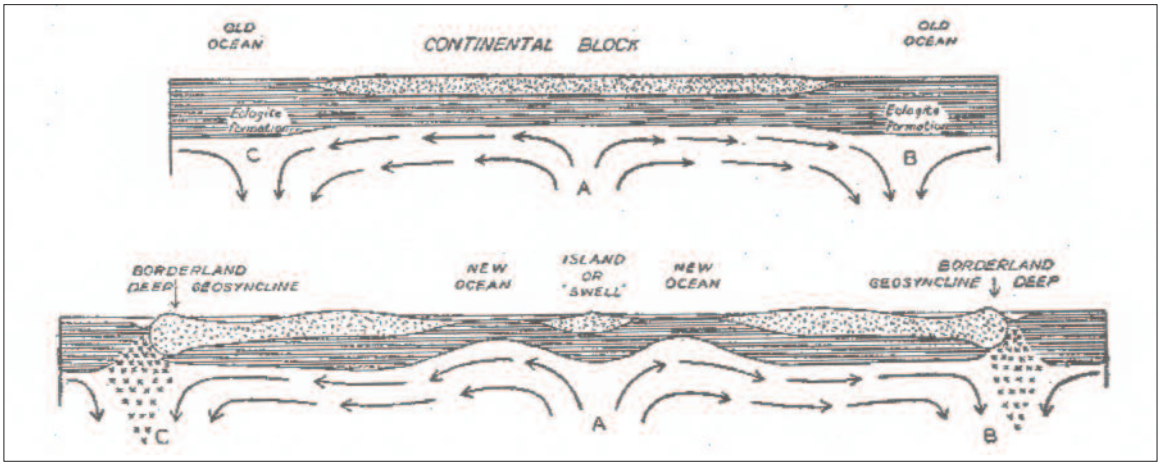


*Figure 53 Holmes' diagram of continental drift from his paper 'Radioactivity and Earth movements' (*Trans Geol Soc Glasgow *1929) (author scan).*

evolution of the crust, so it was no surprise that he should choose to make the issue his priority, particularly since the age of the Earth had been 'resolved'.

While many geologists considered the geological evidence strongly supported the theory of continental drift, most still rejected it owing to a lack of understanding about how continents could move about the globe. Holmes' knowledge of processes within the Earth's interior through his work on radioactivity, geological time and petrogenesis convinced him of its validity. He was the first to propose that slow-moving convection currents in the mantle caused sufficient force to drag continents apart, material from the mantle rising to fill the gaps in the ocean floor. He presented his theory to the Edinburgh Geological Society in December 1927 in a paper entitled 'Radioactivity and geology'. His theories were largely ignored at the time, but he still taught them to his students for the next 30 years (Fig. 53).

Although Holmes was more interested in geology on a global scale, he still published works on local geology, such as 'The Age and Composition of the Whin Sill and Related Dykes of the North of England' (*Mineral Mag* **21**, 1928) and 'The Tholeiite Dykes of the North of England' (*Mineral Mag* **22**, 1929). He continued to promote geology to the general public and in 1929 he broadcast nine half-hour lessons in 'Geology for Schools', on Friday afternoons, for the BBC from the Main Transmitting Station in an old maternity hospital in Newcastle. In 1930 he took the temporary post of Exchange Professor at the University of Basle. Continuing to develop the geology department at Durham, in 1933 he appointed Dr Doris Reynolds to the teaching staff as Lecturer in Petrology. He had first met and been impressed by Dr Reynolds, already and accomplished geologist, while on a field trip to Ardnamurchan in 1931.

In 1932 he was invited to Harvard University to deliver the Lowell Lectures on geology and radioactivity. That same year, still trying to improve his rock-dating technique, he proposed his 'new key to petrogenesis', describing a principle now known as initial ratios. Unfortunately, he illustrated his ideas with an assumed radioactive decay series ($^{41}K/^{41}Ca$), which later proved to be incorrect. As a result of this error the idea that underpins isotope geochemistry was also ignored for 30 years.

In 1838 his wife, Margaret, died. Within a year he had remarried, his second wife being Doris Reynolds, with whom he had developed a relationship some while earlier, and the scandal surrounding which shadowed their life for several years afterward (Fig. 54).

During World War II Holmes continued his work on the age of the Earth and, along with his new wife, became involved in the 'granitisation' controversy, developing a theory about how granite formed within the Earth's crust. Holmes was awarded the Murchison Medal in 1940, became a Fellow of the Royal Society in 1942 and was commissioned by the British government to write a book on physical geology for Royal Air Force officer cadets. In June of that year began writing his world-famous textbook, *Principles of Physical Geology*, a task he performed while 'firewatching'. This involved standing in a high position during air raids, telephoning the locations of fires to the fire brigade. In October 1943 he left Durham on his appointment as Regius Professor of Geology at Edinburgh University, his wife taking up the position of Honorary Research Fellow at the same institution. On 26 September 1944 the first edition of *Principles of Physical Geology* appeared, including, following much deliberation, a final chapter on 'Continental Drift'.

Described as a brilliant and lucid lecturer, Holmes undertook little, if any, fieldwork. He and Doris moved to West Mains Road in 1945, a mere 100 yards from the Grant Institute, his place of work, where he continued to work on the age of the Earth, and by 1946 he had revised the figure to 3,000Ma using measurements of the relative abundance of uranium isotopes. His method is now known as the Holmes–Houterman model, after Fritz Houterman, who published in the same year. The following year he produced the Phanerozoic time-scale.

Despite declining health in Edinburgh, Holmes produced some of his most important work there. Besides that on the age of the Earth, he also published on the geological time scale, the geology of alkali rocks of Africa and, more significantly, on the correlation of the Precambrian shield areas of the world. He made little further comment on continental drift other than a book review in *Nature* (1953) under the heading 'The South Atlantic: land bridges or continental drift?', confessing "I have never succeeded in freeing myself from a nagging prejudice against continental drift."

On his retirement in 1956 he became Emeritus Professor and was awarded the Wollaston Medal by the Geological Society of London and the Penrose Medal by the Geological Society of America. Following his retirement he completely rewrote his *Principles of Physical Geology* for its second edition. Meanwhile, in November 1962, Harry Hess published his *History of Ocean Basins*, in which he proposed the theory of seafloor spreading out of which plate tectonics was born, validating Holmes' theories. In 1964 Holmes

Figure 54 Holmes' second wife, Doris Reynolds (untraced Web source).

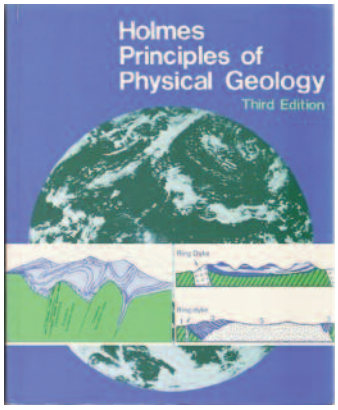


Figure 55 (top) Cover of the third edition of Principles of Physical Geology *(1978) (author scan).*

was awarded the Vetlesen Prize, considered the geological equivalent of a Nobel Prize, by Columbia University's Lamont-Doherty Earth Observatory 'For Achievements in the Science of the Earth and the Universe.'

Curiously, at none of the presentations of his many awards was any mention made of his work on continental drift, perhaps because he was considered nonconformist for his persistent belief in his theory. His commendations were for being the 'Father of the Geological Timescale'. When the second edition of *Principles of Physical Geology* was published in 1965 he only noted in it that, "mantle currents are no longer regarded as inadmissible."

Holmes died in London a few months later on 20 September 1965. Today he is regarded as one of the most important geoscientists of the 20th century. The second edition of his *Principles of Physical Geology* was reprinted six times, becoming essential reading for geology students. A third edition (edited by Doris Holmes) was published in 1978 (Fig. 55) and a fourth edition in 1993. Arthur Holmes is remembered in many places. As well as the Metropolitan Borough Council's blue plaque on his house in Gateshead (placed in 2005), at Durham University there is the Arthur Holmes Isotope Geology Laboratory and the Earth Science students run the Arthur Holmes Geological Society. In 1973 a crater on Mars was named after him (75° 0′ 0″ S, 293° 12′ 0″ W). The European Union of Geosciences created the Arthur Holmes Medal in 1983 (Fig. 56), awarded for Exceptional International Standing in Solid Earth Geosciences, his portrait hangs in the Arthur Holmes Room at the Geological Society of London and there is an Arthur Holmes exhibit at the Grant Institute, University of Edinburgh.

"It is perhaps a little indelicate to ask of our Mother Earth her age, but Science acknowledges no shame." — Arthur Holmes 1913 (Aged 23)

"Looking back it is a slight consolation for the disabilities of growing old to notice that the Earth has grown much more rapidly than I have — from about six thousand years when I was ten, to four or five billion years by the time I reached sixty." — Arthur Holmes 1964 (aged 74) (Fig. 57).

Figure 56 The Arthur Holmes Medal (image courtesy European Geosciences Union; www.egu.eu/awards-medals/arthur-holmes/).
Figure 57 Arthur Holmes 1960 (reproduced by permission of the University of Edinburgh School of Geosciences).

Finally, I focus on two 20-century geologists, sadly no longer with us, whose work has contributed greatly to our knowledge and understanding of the geology of north-east England, and brought them international recognition.

Kingsley Charles Dunham (1910–2001)

Figure 58 Kingsley Charles Dunham (© National Portrait Gallery copyright, Creative Commons licence).

Kingsley Dunham was born at Newton House, Sturminster Newton, Dorset, on 2 January 1910, the son of estate manager, Ernest Pedder Dunham and his wife, Edith Agnes Humphreys, a schoolteacher (Fig. 58). His father trained as an estate manager at the Duke of Bedford's office in Trafalgar Square before moving to Dorset to help manage the Pitt-Rivers estate. In 1913 he was appointed to Lord Boyne's estate office at Brancepeth near Durham. The estate was later sold to the Duke of Westminster but Ernest stayed on as agent for the rest of his career.

Dunham joined Brancepeth Village School on the estate when he was seven years old. He sat for a County Scholarship in 1921, which he won and entered Durham Johnston School. He was particularly interested in physical science and mathematics. Music was his main hobby and he was taught the organ by Canon Precentor A. D. Culley at Durham Cathedral (Dunham's mother was a chapel organist). Dunham was also a chorister at St Brandon's Church, Brancepeth. He was head of school in 1927 and won a Durham University Open Foundation Scholarship in 1927, going on to be a scholar and later organ scholar at Hatfield College, University of Durham.

Dunham read honours in chemistry with two auxiliary subjects — physics and geology. It was the geology that he really enjoyed. Lectures were by Professor Arthur Holmes — Dunham was Holmes' second student; practicals and fieldwork were with Dr William Hopkins. These studies determined his future and at the end of the first year, encouraged to continue with geology, he became the only honours geology candidate in his year, receiving almost one to one tutoring from Holmes and Hopkins.

He graduated in 1930 with a First-class Honours BSc and was offered a postgraduate studentship at Durham supervised by Holmes. The subject of his postgraduate thesis was the genesis of the lead-zinc-fluospar mineralisation in the North Pennine Orefield, an area with which he maintained a lifelong association. Dunham used a small Morris car to visit all the underground mines, adit dumps and shaft heaps in the west Durham orefield (Fig. 59, *on page 51*). He discovered that the vein minerals appeared to be in two distinct zones: the fluorspar zone and the barytes/witherite zone. From similarities with the minerals associated with granites in Devon and Cornwall he suggested that there might be granite beneath Weardale (*see below*).

He accompanied Holmes on his trip to Ardnamurchan in 1931, where the evenings in the hotel were often spent playing party games. Holmes and Dunham amused other party members, including Doris Reynolds (*see above*), by playing four-handed piano duets during games of musical chairs and musical statues.

After submitting his doctoral thesis Dunham was awarded a Commonwealth Fund Fellowship to work on mineralogy at Harvard University; his PhD was conferred 'in absentia' in 1932.

OUGS Moyra Eldridge Photographic Competition 2014

Winning and Highly Commended photographs for 2014

Presented at the OUGS AGM, 29 March 2014 in Edinburgh

Geologically Inspired Landscape, Winner — Dr Ian Williamson

'Below the Old Volcano: Elgol Shore, Isle of Skye'

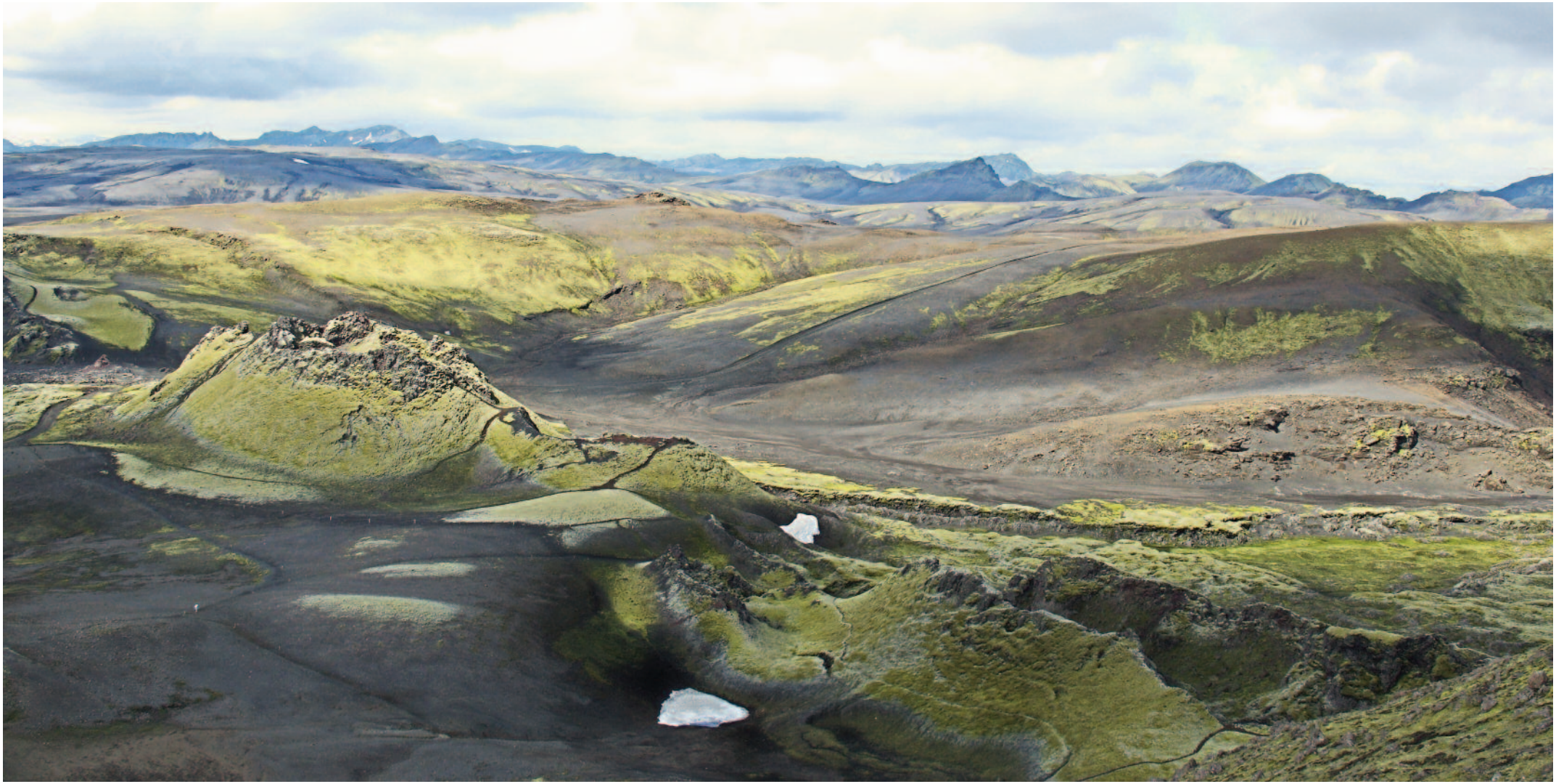
The photograph shows two contrasting elements of Skye's spectacular geology.

It was taken in May 2013 during the OUGS Field Trip to Skye. The view, taken from south of Elgol village on the Strathaird Peninsula, looks north along the rocky foreshore and across Loch Scavaig. The title alludes to the fact that the foreground sedimentary rocks both geologically, and here pictorially, 'underlie' the igneous rocks of the volcano.

The sedimentary rocks in the foreground show trough-style cross-bedding in the Middle Jurassic (Bajocian) Bearreraig Sandstone Formation. Within the Inner Hebrides Basin this formation comprises large- and small-scale cross-stratified sandstones with regularly spaced mud drapes. Bedding structures are bimodal and best explained as the effects of the divergent currents typical of a shallow marine, tidally dominated depositional environment. In the distance along the skyline are the jagged outlines of the Cuillin Hills. The Cuillins are the eroded remnants of the intrusive heart of a Palaeocene volcano, one of several in north-west Scotland. This iconic landscape has been controlled and fashioned as much by the effects of Pleistocene glaciations and post-glacial processes as the contrasting nature of the rocks themselves.

Geologically Inspired Landscape, Highly Commended — Michael Perkins

'The Eastern Rift Zone, Icland'
View looking south across Alftavatn descending from the Hraftinnusker plateau, with the Myrdalsjökull glacier seen on the left. The Eastern Rift Zone is an incipient ridge jump, taking over from the Western Rift Zone, and a rare glimpse into the processes of mid-ocean spreading on dry land.



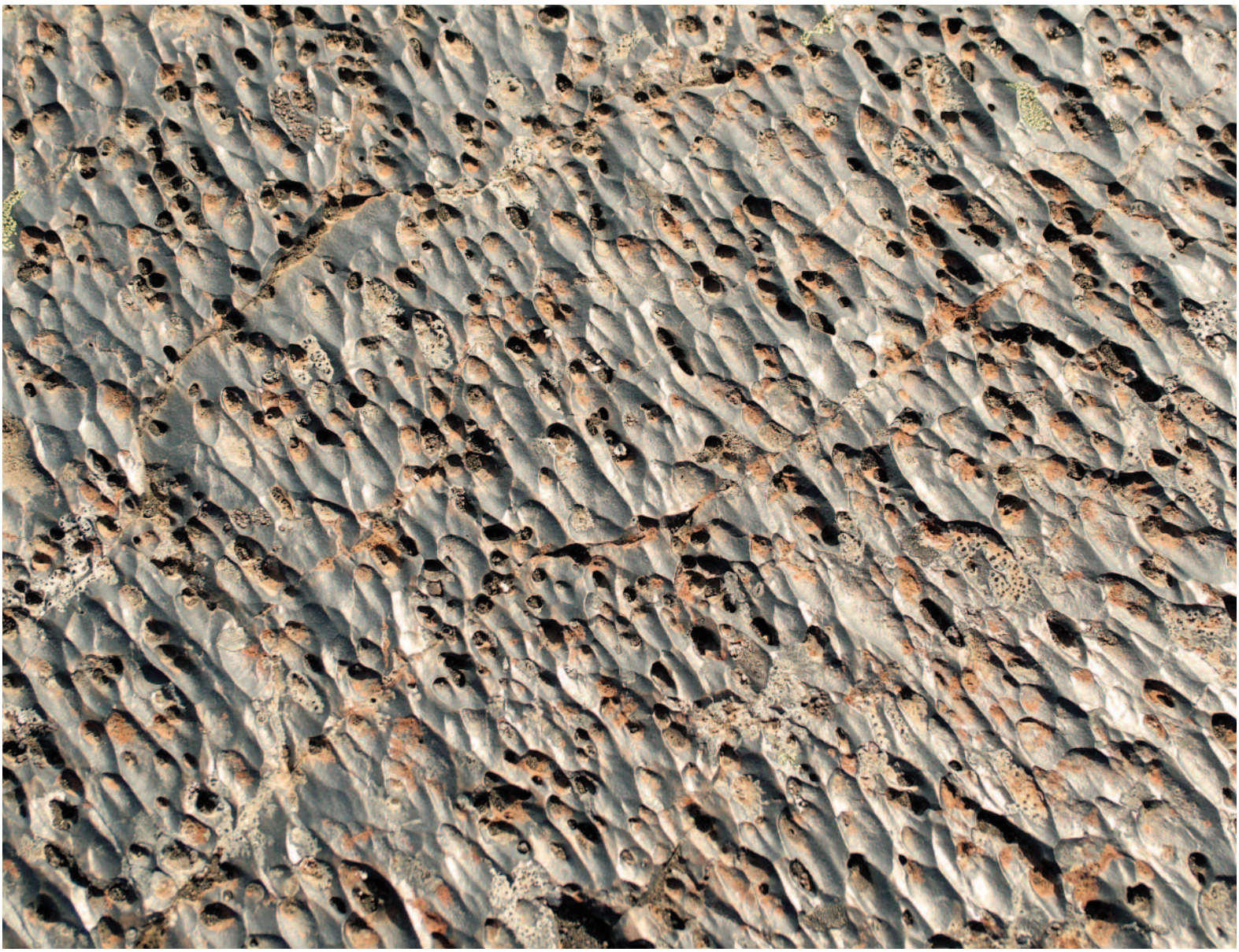
Geologically Inspired Landscape, Highly Commended — Dr Ian Williamsons

'Lava landscape: Laki, Iceland'

The photograph is a panoramic vista with an amazing mix of old and new landforms forms.

It was taken in July 2013 from the summit of Laki, which rises some 200m above its immediate surroundings in southern Iceland; the view is to the north-west and north, shot while on a Volcanic Margins Research Consortium expedition to Iceland to examine lava-sediment interactions. The title is an alliterative evocation of the landscape itself.

This bleak, forbidding landscape is clearly dominated by basaltic volcanism, comprising mile upon mile of dark grey rocks — lavas and tephras — for as far as the eye can see. There are jagged, dark and forbidding-looking volcanic peaks, lines of reddish-brown and orange-yellow tephra cones with a dense covering of bright green moss, dark grey carpets of unvegetated tephra, paler grey and crenulated swathes of the extensive Laki flow and several lakes reflecting the dappled afternoon sunlight. Superimpose an active volcano spouting a curtain of fire in the distance and the scene would have fitted one from the vivid imagination of Tolkien.



Geological Feature or Structure, Winner — Dr Ian Williamson

'Basalt Bubbles: Askja, Iceland'

This close-up photograph shows the aesthetic beauty in the detail of a chilled surface of a vesicular lava flow.

It taken in August 2008 during a pre-Greenland Expedition meeting of the Volcanic Margins Research Consortium. The location was off-road exposures of an historical lava flow seen on the near approach to the stratovolcano of Askja in the central highlands of Iceland. The title describes the rock — lava (basalt) and vesicles (bubbles).

It shows chilled, glassy basalt with numerous closely-spaced vesicles — bubbles of volcanic gas frozen in time. Such structures are common in basaltic lavas and form when gas is released as the flow solidifies; they can form on the upper surface of a flow, within portions of the flow or at its base. They may, if they are ovoid in shape, as in this photograph, suggest the direction of flow. Preserved in the rain shadow north-east of Vatnajökull glacier, the area receives only about 450mm of rainfall annually, so weathering is minimal (some oxidation) and there is only a hint of lichen growth.

Geological Feature or Structure, Highly Commended — Dr Ian Williamson

‘Pillows and blankets: Laugarvatnshellir, Iceland’

This photograph shows pillow lavas overlain (draped) by red-brown weathering, finely-bedded hyaloclastite sandstone.

It was taken in July 2013 while on a Volcanic Margins Research Consortium expedition to Iceland to examine lava-sediment interactions. The sequence shown is exposed at Laugarvatnshellir (plains of warm spring valley), 22km south-east of Thingvellir (Þingvellir) in south-west Iceland. The title is a light-hearted play on ‘bedforms’ or ‘bedding’.

These rocks form part of the laterally changing facies typical of an hyaloclastite ridge — an association of volcanic and volcaniclastic sedimentary rocks associated with sub-glacial volcanism. The basic units formed in basaltic eruptions under glaciers are pillow lava, hyaloclastite, irregular intrusions and capping lava flows. Pillow lava commonly represents the basal unit of subglacial mountains with overlying chaotic or stratified hyaloclastites.

During glaciations, hyaloclastite ridges are formed instead of long crater rows such as seen at Laki. Subglacial eruptions cause melting in holes in the ice sheet and, owing to interaction between (hot) magma and (cold) melt water, the magma disintegrates into fine sand and ash-like particles, which accumulate inside the cavity formed by the melting glacier. Pillows form where disintegration caused by thermal granulation and fuel-coolant interaction is suppressed owing to high water pressures.

Industrial Geology, Winner — Dr Ian Williamson

'Geotourism with bite: Neuguen Province, Patagonia, Argentina'
This photograph of a large road sign uses local geology to welcome visitors to the town of Villa el Chocón in the north-western Argentine part of Patagonia.

It was taken in 2007 while on an exploratory visit to the area to investigate lava-sediment interactions in hydrocarbon-prone sedimentary basins. The title alludes to the fact that small settlements such as Villa el Chocón often struggle economically and so it is perhaps of no great surprise to see that they have readily (and quite spectacularly) seized upon the discovery of significant dinosaur remains locally to advertise and promote the area.

The dinosaur-bearing rocks of the area are of Early–Late Cretaceous (Albian) age and are assigned to the Candeleros Member, Rio Limay Formation, Neuquen Group. This is a temperate, continental red bed sequence of siliciclastic aeolian and fluvial sediments. They form part of the larger Neuquen Basin and were laid down during alternate rainy and dry periods. Many fossils were found during the construction of the Ezequiel Ramos Mexía dam on the Limay River and today the site of one of the main hydroelectric power plants in Argentina. Prominent among these finds was the large theropod *Gigantosaurus carolonni*, and this and others may be seen at the town's Ernesto Bachmann Palaeontological Museum.

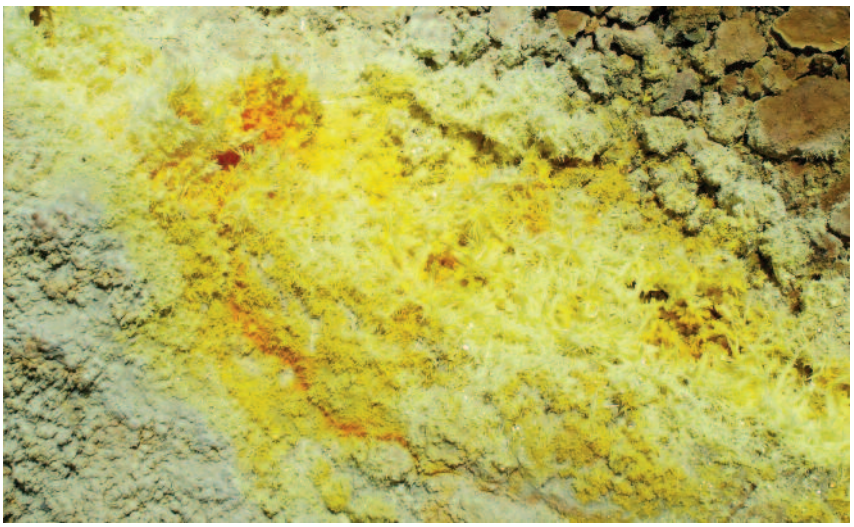
Mineral, rock or fossil, or thin section/SEM view, Winner: Sandra Morgan--
[sponsored by Prof. Tony Grindrod]

'Bourgetia'
Found at Hitchcopse Pit, Oxfordshire (Field of view 20mm) (Sandra Morgan)

Hitchcopse Pit is a nature reserve on the site of a former quarry near Abingdon, Oxfordshire. Participants in an OUGS field trip in October 2012, led by Jill Eyers, carried out geological logging at the site in response to a request from Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust.

In the quarry is an exposure of a sequence of Corallian rock (Upper Jurassic). This rock sequence was laid down in a shallow tropical sea, and the fossil Bourgetia, a marine gastropod, was found in the Lower Trigonia rock layer of the Corallian sequence.

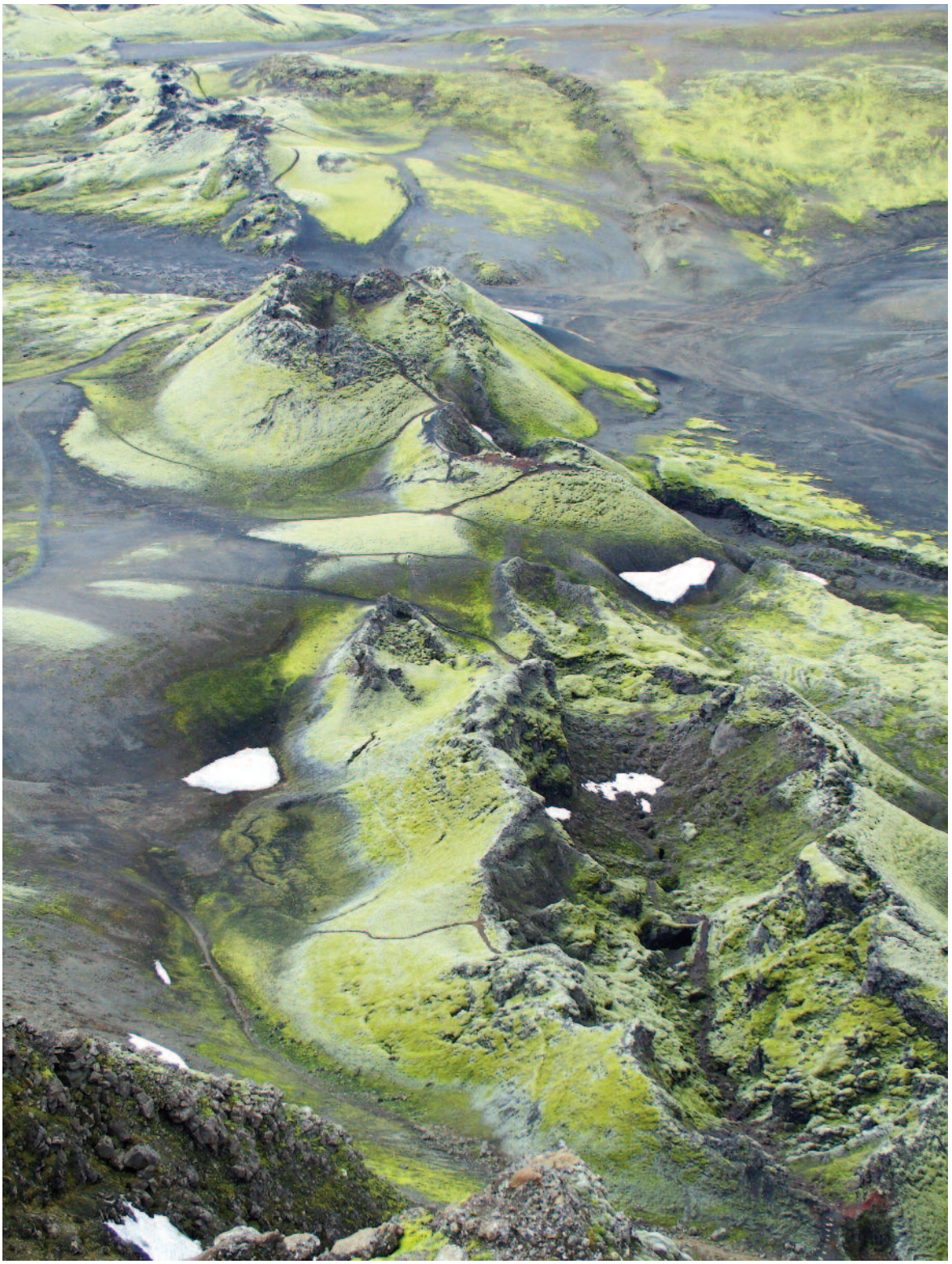
Mineral, rock or fossil, or thin section/SEM view, Highly Commended — Dr Ian Williamson
[sponsored by Prof. Tony Grindrod]



'Brimstone: volcano, Aeolian Islands, Italy'
This photograph shows a close-up of a Sulphur-crystal-lined fumarole on Vulcano, a small island in the Tyrrhenian Sea to the north of Sicily.

The fumarole is close to the summit of the island's Gran Cratere, the so-called Fosse Cone — a large dormant tephra cone. Fumarolic Sulphur is the result of the exhalation and sublimation of hot volcanic gases and, as here, the mineral often appears in its native crystalline, somewhat dendritic form. Taken in June 2009, the title alludes to the wonderful yellow colour as well as the more biblical name for the element.

Vulcano is one of eight volcanic islands making up the Aeolian Islands or Arc. They form one of the most active geological structures in the Mediterranean, owing their existence to the dynamic tectonic regime; they result from the collision of the African and Eurasian plates. Vulcano is currently quiescent, although there is still some fumarolic activity; it last erupted in 1888–90. It lends its name to a particular eruptive style — Vulcanian — whereby the volcano erupts in a series of discrete, violent but short-lived, canon-like explosions, frequently ejecting large bombs and blocks as well as ash clouds.



Popular Vote, Winner — Dr Ian Williamson
(by AGM delegates)

'Life returns: Laki fissure system, Iceland'
The photograph shows a number of cinder and spatter cones produced during the Laki (Lakagígar) eruptions of 1783–84.

It was taken in July 2013 from the summit of Laki, which rises some 200m above its immediate surroundings in southern Iceland; the view is south-west, taken while on a Volcanic Margins Research Consortium expedition to Iceland to examine lava-sediment interactions. The title refers to the fact that despite being obliterated by the eruptions, life, manifesting here in the form of a thick blanket of bright green moss, is slowly re-establishing itself on the volcano.

The tephra cones form part of a 27km long cone row, which developed along a series of *en échelon* fissures associated with the Grímsvötn volcano in southern Iceland. As well as some 15km^3 of basaltic lava, the eruptions produced spectacular fire-fountaining'— the famous Skaftáreldar or 'Skaftá fires'. Ash and poisonous gases emanating from the eight-month-long eruption killed over half of Iceland's livestock, contributing to a famine that killed approximately 20% of the island's population. There was also widespread disruption, environmental damage and climatic perturbations over much of the northern hemisphere.

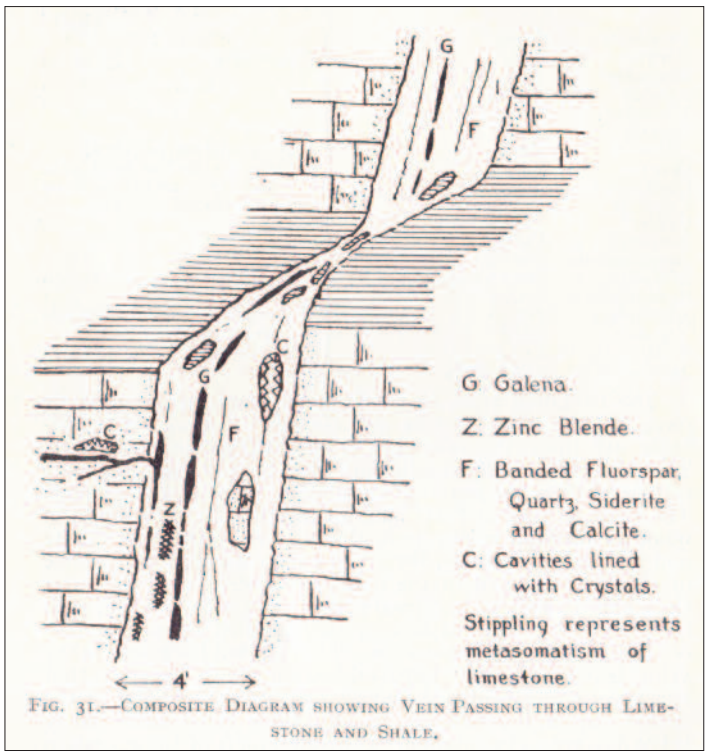


FIG. 31.—COMPOSITE DIAGRAM SHOWING VEIN PASSING THROUGH LIMESTONE AND SHALE.

Figure 59 A diagram from Dunham's contribution to The Geology of Northumberland and Durham *(chapter X 'Mineral Deposits of the North Pennines' (*Proc Geol Assoc ***42** *(3), 1931) (author scan).*

While at Harvard he travelled widely from Mexico to Canada and completed a geological survey of the Organ Mountains of New Mexico for the Bureau of Mines. He graduated with a Master of Science degree (MS) in Mining Engineering in 1933 and in 1935 Harvard also awarded him a Science Doctorate (SD) for his thesis on Organ Mountains mineralisation (Fig. 60).

Returning to Britain in June 1935, Dunham obtained a post as a geologist with the Geological Survey of Great Britain. He started by mapping the Old Red Sandstone around Chepstow before later investigating the haematite ores of Cumbria. He was unimpressed with the previous mapping of the area, regarding it as a "remarkably feeble effort", as the haematite deposits had been ignored.

In 1936 he married Margaret Young of Choppington, Northumberland (and St Mary's College, Durham), and two years later, on the 2 August 1938 in Newcastle, his son Ansel Charles Dunham was born. During World War II Dunham served as a captain in the 22 Durhams, Home Guard; later he was posted to the 4 Hertfordshire Battalion and promoted to Major. He was awarded the Defence Medal for his service (Figs 61 and 62).

He also undertook detailed investigations of the mineral resources of the North Pennines, with the assistance of a drilling rig and crew supplied by the Canadian Army. On his recommendation they began recovering zinc from old mine heaps at Nenthead.

After World War II Dunham was transferred to the London office, commuting from the house he had built in Welwyn Garden City. He was awarded an Honorary DSc by Durham University in 1946 as part of the Centenary of the founding of Hatfield College. In 1948 his work on the north of England mineral deposits was published in *The Geology of the Northern Pennine Orefield, Volume 1*, probably his most notable work. That same year he became Chief Petrographer of the Survey and was also

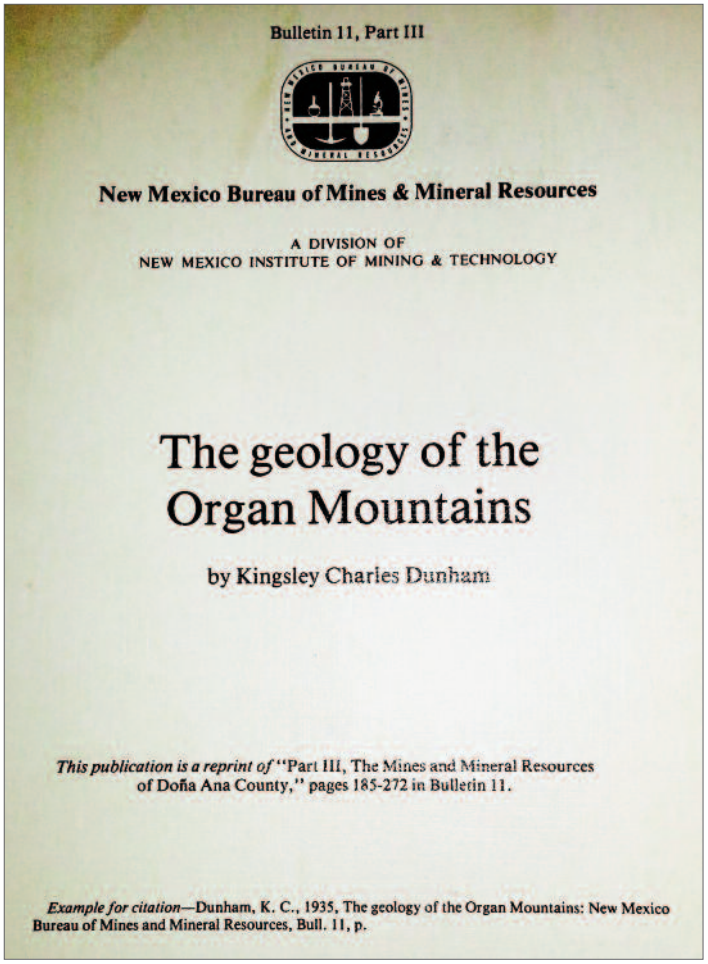
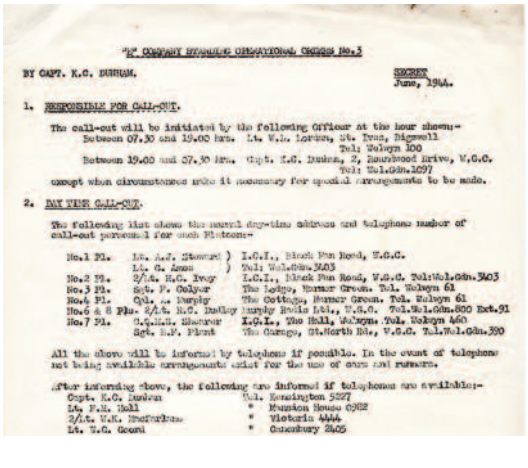

Bulletin 11, Part III
New Mexico Bureau of Mines & Mineral Resources
A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY
The geology of the Organ Mountains
by Kingsley Charles Dunham
This publication is a reprint of "Part III, The Mines and Mineral Resources of Doña Ana County," pages 185-272 in Bulletin 11.
Example for citation—Dunham, K. C., 1935, The geology of the Organ Mountains: New Mexico Bureau of Mines and Mineral Resources, Bull. 11, p.

Figure 60 Front cover of Dunham's Organ Mountains*, NM survey report (author scan).*

given responsibility for handling the opening and closing sessions at the 18 International Geological Congress held in London, in the Albert Hall. At the last minute, the organist was unable to come, so Dunham stepped in and played the Trumpet Voluntary by Jeremiah Clarke, an event that he regarded as a great moment in his life.

Dunham returned to Durham University when the Chair of Geology became vacant in 1950. He was reluctant to take the post, even at interview, but, according to G. A. L. Johnson in his *Biographical Memoirs of Fellows of the Royal Society* (2003),

Figure 61 Dunham's Standing Operational Orders, "E" Company, June 1944, as Capt. K. C. Dunham (© NERC (BGS) (non-commercial use).
Figure 62 Dunham's Defence Medal (© NERC (BGS) (non-commercial use).


"E" COMPANY STANDING OPERATIONAL ORDERS No.5

BY CAPT. K.C. DUNHAM. SECRET June, 1944.

1. RESPONSIBLE FOR CALL-OUT.

The call-out will be initiated by the following Officer at the hour shown:-
Between 07.30 and 19.00 hrs. Lt. W.H. Lorden, 26, Frog, Digswell Tel: Welwyn 100
Between 19.00 and 07.30 hrs. Capt. K.C. Dunham, 2, Beechwood Avenue, W.G.C. Tel: Welwyn 1097
except when circumstances make it necessary for special arrangements to be made.

2. KEY MEN CALL-OUT.

The following list shows the normal day-time address and telephone number of call-out personnel for each Platoon:-

No.1 Pl. Lt. A.J. Stewart) Lt. C. Lees) I.C.I., Black Pan Road, W.G.C. Tel: Welwyn 3403
No.2 Pl. S/Sgt. R.C. Ivey I.C.I., Black Pan Road, W.G.C. Tel: Welwyn 3403
No.3 Pl. Sgt. F. Collyer The Lodge, Manor Green. Tel. Welwyn 61
No.4 Pl. Cpl. J. Murphy The Cottage, Manor Green. Tel. Welwyn 61
No.5 & 6 Pls. S/Sgt. R.C. Dudley Murphy Brolo Ltd., W.G.C. Tel: Welwyn 800 Ext. 91
No.7 Pl. C.Q.M.S. Shorrock Sgt. R.P. Plant E.M.I., The Hall, Welwyn. Tel. Welwyn 460 The Garage, St. North Rd, W.G.C. Tel: Welwyn 390

All the above will be informed by telephone if possible. In the event of telephone not being available arrangements exist for the use of cars and runners.

After informing above, the following are informed if telephones are available:-
Capt. K.C. Dunham Tel. Kensington 5227
Lt. F.H. Hall " Mansion House 0902
S/Sgt. W.H. Rutherford " Victoria 4444
Lt. W.G. Grant " Canonbury 2405

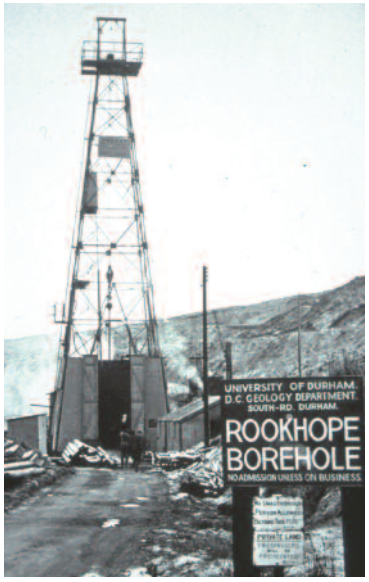


Figure 63 The Rookhope borehole (© Durham University, with kind permission).

Figure 64 The Royal Society Medal (untraced Web source).

it is said that he was swayed by the scenery with the flowering rhododendrons on the banks of the Wear. While there he planned and supervised the construction of the new geology and chemistry building. Under Dunham's tenure the department was expanded with new branches of geophysics and engineering geology. He often led up to 130 students on fieldwork mapping in Westmorland or on strenuous treks over the Pennines. In recognition of his scientific work he was awarded the Bigsby Medal of the Geological Society of London in 1954 and elected a Fellow of the Royal Society in 1955.

In 1956 Dunham returned to the USA for a year, as George Miller Foundation visiting Professor of Structural Geology at the University of Illinois at Urbana. After his return to Durham, he became President of the Yorkshire Geological Society (1958–9). He was an excellent administrator and was always concerned for the welfare of his staff and students, serving on many university committees and as Sub-Warden from 1959 to 1961.

The zoning of minerals within the North Pennines had been observed by generations of miners. During his PhD research Dunham had postulated that this could be explained by the presence of a deep granitic body within the region. In the intervening years, advances in geology, particularly in geophysics, gave support to this hypothesis and suggested granite may be present between 300m and 600m beneath Rookhope. In 1960–61 Dunham helped secure Government funding to undertake a drilling project at Rookhope, which discovered granite at 390.5m, a discovery that led to a rethink of the origins of similar ore deposits worldwide (Fig. 63).

In 1963 the Nature Conservancy published *The Geology of Moor House*, a comprehensive memoir of the Nature Reserve co-authored by Dunham and G. A. L. Johnson. Also that year, Dunham received the Sorby Medal and became President of the Institute of Mining and Metallurgy (1963–4); and shortly after that, he was elected President of the Geological Society of London (1966–8), and received their Murchison Medal.

In 1967 Dunham returned to the Geological Survey (renamed the Institute of Geological Sciences in 1965, when it was merged with the Geological Museum and Overseas Geological Surveys) as its Director, where he organised and oversaw the expansion of the Survey, but he also maintained his strong connection to Durham University and was made Professor Emeritus in 1968.

Under Dunham's directorship new Survey laboratories and storage facilities were planned, as well as expansion into new fields of geology such as geophysics, geochemistry and marine geology. Dunham was instrumental in choosing a new headquarters office outside London to house his expanding Institute of Geological Sciences. His preference was for Nottingham and while on a flight to Washington DC he saw an advert for a modern training college for sale at Keyworth, near Nottingham. This became the new headquarters of the Survey. At Keyworth many Survey staff were seconded with the Overseas Division and Dunham made a point of visiting them. In 1969 alone he visited Malaya, Ceylon, Uganda, Zambia and the Solomon Isles. In 1970 he received the Royal Medal from the Royal Society "In recognition of his distinguished contributions to pure and applied geology, and especially in the field of metallic ore deposits". He was their Vice-President for five years from 1971, and was knighted in 1972 (Fig. 64).

In 1973, while President of the International Union of Geological Sciences, he was invited to be the Commencement Speaker at the University of Michigan's graduation ceremony, at which U. Michigan conferred upon him the degree Doctor of Science. The subject of his speech was that the effect of world-wide population and economic growth outstripping natural resources would be famine and/or pollution that could lead to mass death within decades. His belief was that the solution would not be through scientific advancement but through personal choice, accepting austerity over consumerism. (We are now 40 years on from this foresight!)

Dunham retired from the Geological Survey in 1975 and returned to Durham, to undergraduate teaching as Emeritus Professor. His home at Charleycroft, Quarryheads Lane, Durham had been extended to provide more office and library space. In 1976 he was elected to Honorary Membership of the Yorkshire Geological Society and received the Wollaston Medal of the Geological Society of London. A major event was held to celebrate his 75 birthday. More than 100 old students and colleagues came to Durham and presented a programme of lectures based on their current work, and published these as *Geology in the Real World: the Kingsley Dunham Volume: papers presented at the Dunham-Durham Reunion, 14–17 April 1985, to commemorate the seventy-fifth birthday of Sir Kingsley Dunham, F.R.S.*

The Institute of Geological Sciences retained Dunham for three years following his retirement so he could complete the survey of the Askrigg Orefield (Fig. 65). He was assisted in this work by his former student, Dr A. A. Wilson. There was much strenuous

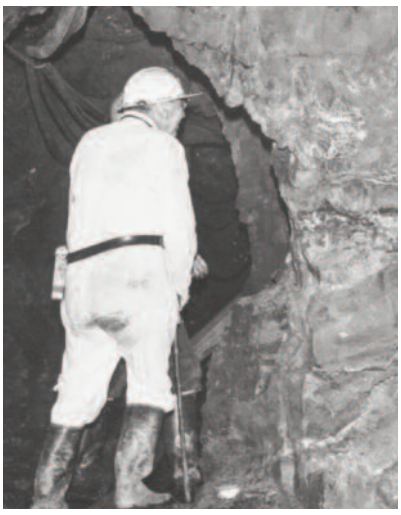


Figure 65 Sir Kingsley Dunham inspecting a galena flat on Diana Vein in the Great Limestone in the wall of the BSC Main Haulage Level on 13 September 1979, just before the mine closed. (photo by Dave Greenwood, reproduced with permission).

Figure 66 Portrait of Sir Kingsley Charles Dunham (by Nicholas Leake, 1998. BBC/Public Catalogue Foundation; © Durham University, with kind permission).

field work for the ageing Dunham, but it has been said that, "Luckily, Sir Kingsley was already a skilled tumbler who could fall and land softly, usually not hurting himself." This work culminated in the second volume of *The Geology of the Northern Pennine Orefield* (1985). He also completed a much-revised version of the first volume in 1990. With his eyesight failing rapidly, it became increasingly difficult for him to add to his already impressive list of more than 200 publications.

Dunham continued to attend events such as the Arthur Holmes Geological Society lectures at Durham University; and he maintained his interest in music, frequently visiting Durham Cathedral on his own. He was often seen feeling his way around the cloisters, unable to see in the semi-darkness. His love of the Cathedral went back to his organ-playing student days and he had a great knowledge of its history, architecture and building stones. Dunham often led visitors on Cathedral tours, including weekly ones for Open University Summer Schools (for whom he was also an advisor) (Fig. 66).

On 18 January 1998 his son Ansel, Professor of Industrial Mineralogy at the University of Leicester, died of cancer, aged 59. In November the same year his wife passed away, after a long illness, aged 90. Sir Kingsley Charles Dunham himself died on 5 of April 2001, aged 91 and is buried in Brancepeth.

At the time of his death he held no fewer than 12 honorary doctorates from universities in Britain and abroad. Two laboratories at Durham University bear his name: the Sir Kingsley Dunham Palaeoclimate Laboratory and the Sir Kingsley Dunham Earth Imaging Laboratory. The British Geological Survey (as renamed in 1984) headquarters were at the Kingsley Dunham Centre, Nicker Hill, Keyworth, Nottingham. After refurbishment in 2012, the headquarters were renamed the BGS Environmental Science Centre, and its main reception is in the Sir Kingsley Dunham Building.

Thomas Stanley Westoll (1912–1995)

Stanley Westoll was born in West Hartlepool on 3 July 1912 (Fig. 67). His family had lived in the Sunderland area for more than 200 years and had strong associations with the sea. His father, Horace Stanley Westoll, was a mariner and was one of the last to earn a Master's Certificate in both sail and steam. Unfortunately a lung condition prevented him from commanding a ship. After a period as Assistant Dockmaster at Tyne Dock he returned to West Hartlepool as Dockmaster. Westoll's mother Nellie (née Metcalfe) was a schoolteacher from a farming family in the Yorkshire Dales, where the Westolls holidayed.

Figure 67 Thomas Stanley Westoll, 1949 (www.slideshare.net).

Thomas Westoll's interest in geology started at an early age. He recalls receiving

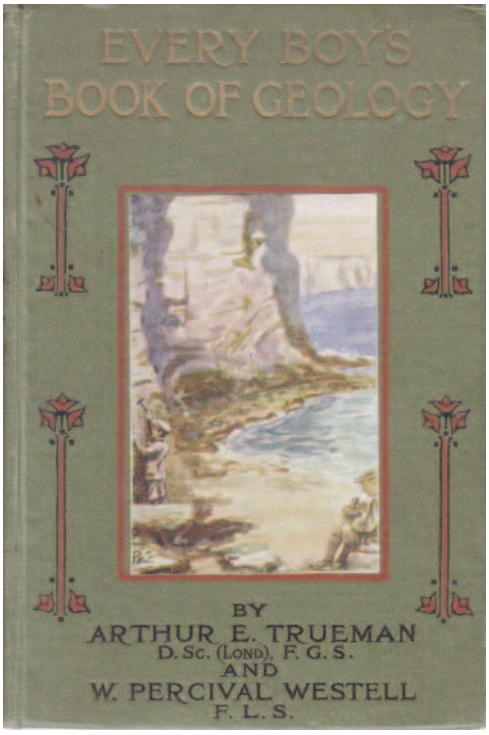


Figure 68 Front cover of the Trueman and Westell book Every Boy's Book of Geology *that was Thomas Westoll's introduction to geology.*

from an uncle, on his tenth birthday, a book by Arthur E. Trueman and W. Percival Westell on rocks and fossils (Fig. 68). Soon after, while on a family holiday in Whitby, young Thomas had collected "a better *Dactylioceras* than that figured in the book." From then on he became a keen collector, using the domestic coal hammer for his fieldwork.

Westoll attended West Hartlepool Secondary School where he was much influenced by his mathematics, chemistry and physics teachers. He was also a good athlete and had trials with the county junior team for rugby. Unfortunately, at the age of 15, he suffered a severe accident — while playing with friends on the high board at the swimming pool, he was pushed off. He fell on the edge of the bath before sinking to the bottom of the pool. He was rescued and resuscitated by the lifeguard. The fall smashed his pelvis and he spent months in traction in hospital (during which time he taught himself Egyptian hieroglyphics!). Because of this accident and operation, however, as he continued to grow, his right leg ended a couple of inches shorter than his left leg.

During his time at school he met C. T. Trechmann, who frequently visited, in his Rolls-Royce, to take a few students out on geology trips (*see above*). He also entered for the Hancock Junior Essay Prize of the Natural History Society of Northumberland, Durham and Newcastle upon Tyne. His piece was entitled 'The geology of the district around West Hartlepool', for which he was awarded a minor prize. He chose E. Neaverson's *Stratigraphical Palaeontology* (1928). His school awarded him the Atheneum Leaving Exhibition Prize at their Speech day in 1929.

In October 1929 he entered Armstrong College, Newcastle upon Tyne, on an Open Entrance Scholarship. While still an undergraduate, he completed his first publication, a petrological appendix to Trechmann's paper 'Notes on Brimstone Hill, St Kitts' (*Geol Mag* **69** (6), 1932). His second publication (with the geologist, archaeologist, industrial historian, and writer Arthur Raistrick) was influenced by Trechmann's interest in archaeology.

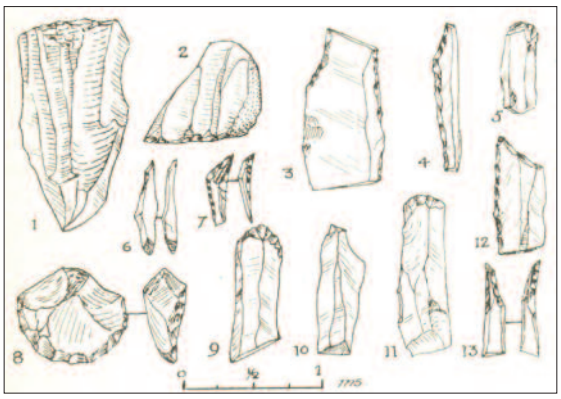


*Figure 69 Drawings of Crimden Dene flints from 'A prehistoric site on the South Durham coast' (*The Vasculum*, 1933) (author scan).*

It was entitled 'A prehistoric site on the South Durham coast' (*The Vasculum* **19**, 1933) and reported on worked flints collected from Crimden [*sic*] Dene (Fig. 69).

Westoll graduated from Armstrong College in 1932 with First-class Honours in Geology, with metallurgy and zoology as subsidiaries; then went straight on to study for a PhD at the University of Durham, on Late Permian fishes from the Marl Slate of Northumberland and Durham. His thesis, *The Permian Palaeoniscid Fauna of Northumberland and Durham*, submitted after only two years, earned him his degree in 1934. Only the abstract was published, however, for apparently Westoll thought that most of his thesis had been appropriated by Hermann Aldinger, a German researcher studying in Stockholm, to whom Westoll had sent a copy of his thesis. Aldinger's thesis, *Late Permian Palaeoniscid Fishes from East Greenland*, referred to 'Westoll 1934' in the text, but did not mention him in the acknowledgements. Aldinger credited the new genus *Reticulolepis* to 'Westoll 1934', but, because Westoll's thesis was unpublished, the new genus became Aldinger's under the Code of Zoological Nomenclature!

In October 1934 Westoll moved to London, having won a Senior Research Award from the Department of Scientific and Industrial Research (DSIR) worth £300 a year. He worked under D. M. S. Watson, Jodrell Professor of Zoology at University College. He spent much of his time at the British Museum (Natural History) visiting E. I. White, who was in charge of fossil fishes. On Saturdays he watched Harlequins play at Twickenham and on Sundays he walked around London. Although he played no instruments, Westoll was musical and joined the English Madrigal Choir while in London. He also made several visits to Oxford where he met E. S. Goodrich, then the leading British comparative anatomist.

Late in 1935 Westoll and fellow researcher, Gunnar Säve-Söderbergh from Stockholm, were invited to spend the weekend with Sir Arthur Smith Woodward, former Keeper of Geology in the British Museum and an expert on fossil fishes. After dinner they were allowed to sign the famous tablecloth on which Lady Smith Woodward had embroidered in silk the signatures of other researchers in the field. The tablecloth (with almost 350 signatures) is now mounted in the Department of Palaeontology at the Natural History Museum. The following week Westoll took Säve-Söderbergh to Newcastle to show him the Hancock Museum collections, then went on to examine collections in Edinburgh, York, Manchester, Paris and Stockholm. In Stockholm he met Hermann Aldinger and found him to be a brilliant, independently minded researcher. Westoll then moved on to Oslo, where he saw the enormous collection of fossil fishes from Spitsbergen before returning to Newcastle via Bergen.

Back in London Westoll began work on a Permian coelacanth and collaborated with William Graham-Smith to study Recent and Devonian lungfishes. He revisited Scotland, studying museum collections and visiting many of the classic Old Red Sandstone fish localities. In Thurso he met Cambridge zoologist C. Forster-Cooper. Westoll records having "had a skinful of port and played billiards" the night before being taken by Forster-Cooper to Achanarras Quarry, a place he would revisit many times. His paper 'On the structures of the dermal ethmoid shield of *Osteolepis*' (*Geol Mag* 1936) put forward his 'theory of cosmine resorption'.

Shiny cosmine covers the dermal bones of *Osteolepis* and many other Devonian crossopterygians. Some specimens have cosmine, others do not; and, perhaps, because of this had often been assigned to different genera or even to different families. Westoll suggested that the cosmine was periodically resorbed, enabling growth, before reforming. Some specimens showed concentric grooves, which he proposed were the stadia of past resorptions. Forster-Cooper immediately adopted Westoll's theory and the grooves are now called Westoll-lines (Fig. 70).

In August 1936 Westoll acted as secretary on the Geologists Association field meeting in Orkney and Shetland. By the end of the year he had produced a substantial paper on the Devonian fishes of the area. The following year, with grants from the Royal and Geological Societies, he made his first trip to North America, where he visited all the major east-coast museums, accompanied part of the time by D. M. S. Watson. In New Brunswick he met up with William Graham-Smith and began doing fieldwork in the Upper Devonian exposures of Scaumenac Bay (Miguasha), a site Graham-Smith had visited in 1934. But Westoll cut short his trip, saying that he had to leave to attend the International Geological Congress in Moscow (21–9 July 1937). Before departing, the pair stopped to discover the Devonian vertebrate fossil locality at D'Aguillon, Quebec, a site later 'rediscovered' by Canadians in 1946. However, the first fish they described from the locality was named *Cephalaspis westolli* in recognition of priority. There is, curiously, no record of Westoll having attended the Moscow Congress.

Graham-Smith and Westoll brought back a part-skull of *Elpistostege watsoni* from Miguasha (the holotype), which Westoll described as the 'missing link' between fishes and tetrapods — for he would not commit to calling the fossil either a fish or a tetrapod (Fig. 71, *opposite*). Until recently only three fragments of the species had ever been found. In 2010, however, a complete specimen was found at Miguasha,

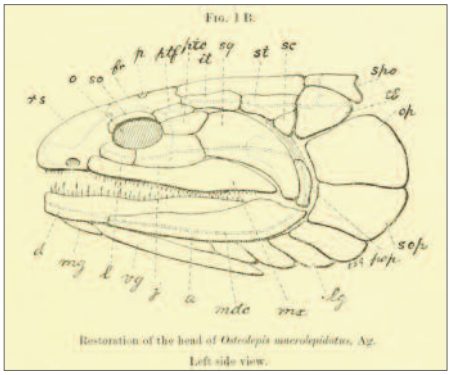


Figure 70 Drawing of an Osteolepis *head (from E. S. Goodrich 1918* J Linnean Soc Zoology **34**; *Internet Archive http://archive.org; reproduced non-profit, for educational purposes only).*

Figure 71 Partial skull of Elpistostege *found by Westoll and Graham-Smith at Miguasha, New Brunswick (© Miguasha National Park 2007; www.miguasha.ca)*

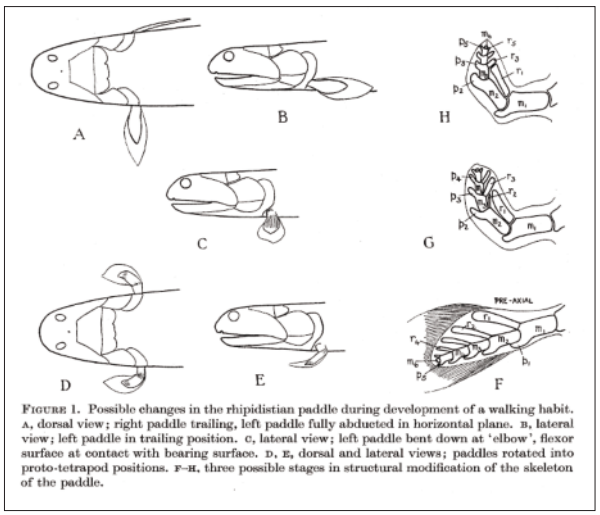


FIGURE 1. Possible changes in the rhipidistian paddle during development of a walking habit. A, dorsal view; right paddle trailing, left paddle fully abducted in horizontal plane. B, lateral view; left paddle in trailing position. C, lateral view; left paddle bent down at 'elbow', flexor surface at contact with bearing surface. D, E, dorsal and lateral views; paddles rotated into proto-tetrapod positions. F–H, three possible stages in structural modification of the skeleton of the paddle.

*Figure 72 Figure 1 from 'The origin of the primitive tetrapod limb' (*Proc Roy Soc Lond *1943; © www.royalsocietypublishing.org, free access. Creative Commons Licence CC-BY-44).*

and modern research techniques have placed *Elpistostege* as the last fish before tetrapods. It was the star of the congress of the Society of Vertebrate Palaeontology (SVP) in Los Angeles in 2013 and has been described as being as important to science as Archaeopteryx or the hominin fossil Lucy (*Australopithecus afarensis*).

Westoll's three-year DSIR award expired in 1937, but that same year he won an 1851 Exhibition Research Fellowship. However, he relinquished this fellowship after only a short time, as he was appointed to a Lectureship in Geology at the University of Aberdeen under Professor T. C. Phemister. The department at Aberdeen was in quite a mess — there had been a fire in 1906 and to Westoll things seemed to be "just as they were left [in 1906]" with "enough work here for a galley slave, & I'm the one."

Soon after arriving in Aberdeen, Westoll met Dorothy Wood, the daughter of a family of Aberdonian trawler owners. They married in December 1939. When World War II broke out Westoll tried to enlist in the army — he passed the medical, but when he requested a special boot when collecting his uniform, his disability was revealed. He joined the Air Raid Precautions instead. Prof. Phemister did join up, leaving Westoll as Acting Head of Department. In Britain, following the torpedoing of the battleship *HMS Royal Oak* in October 1939, Westoll served as geological adviser for the construction of anti-submarine barriers at Scapa Flow. His son, Neil David Stanley, was born in 1941. And in July that year Westoll was awarded a DSc by Aberdeen University for a thesis on 'Late Carboniferous haplolepid fishes'.

In 1942–3 he was elected to fellowships in the Royal Society of Edinburgh (FRSE), the Geological Society of London (FGS) and the SVP. He also completed his extensive publication on 'The origin of the tetrapods' (*Biological Reviews* 1943), although he reported that "it was cut tremendously after acceptance owing to paper-shortage". Also in 1943, he was involved in training for anti-chemical warfare. During this training, overexposure to the noxious gases caused him sinus problems for which he received treatment from 1945–7, but the problem persisted into his old age. Westoll continued to publish throughout the war period, including works on coelacanths, on rhipidistians (Fig. 72), on early amphibian phylogeny and on homologies between palatal bones in reptiles and mammals.

The development of the mammalian ear ossicles became the focus of his work in 1943. He saw that the fish hyomandibular could be transformed into the stapes of the middle-ear. He also suggested that, although very different in appearance, the eardrums in frogs, lizards and mammals were homologous.

Westoll's first monograph was published in 1944 by the American Museum of Natural History, entitled *The Haplolepidae, a New Family of Late Carboniferous Boney Fishes: a Study in Taxonomy and Evolution*. This was a work based on his earlier DSc thesis at Aberdeen (Fig. 73).

On Christmas Eve 1946 Westoll flew across the Atlantic to attend two meetings. The first, in Chicago, was the Sixth Annual Meeting of the SVP. The second was the Conference on Genetics, Palaeontology and Evolution, at Princeton University. At Princeton, Westoll read a paper on lungfish evolution, his paper being the longest of the 23 papers presented. In his presentation he showed that there was rapid evolution in the Devonian and Early Carboniferous followed by much slower change in the Late Carboniferous to Recent. The Conference helped make his name as an evolutionist.

In October 1948 Westoll left the University of Aberdeen to take up the recently vacated 'J. B. Simpson Professor of Geology' post at the University of Newcastle (succeeding H. G. A. Hickling, Westoll's former tutor and supervisor at Armstrong College — part of King's College, Durham from 1937, now part of U Newcastle, since 1963). The department was struggling to cope with the increased influx of students following World War II — it had increased from 90 to 400 in geology. Westoll's wife and son did not come with him to Newcastle, however, and they divorced in 1951. In July the following year Westoll married Barbara Swanson McAdie, a geology graduate working for the Ordnance Geological Survey in London, whom he had met in Achanarras Quarry in the summer of 1948. In September 1952 they sailed to New York on the *Queen Elizabeth*, going on to Harvard University, where Westoll spent a semester as Agassiz Visiting Professor of Vertebrate Palaeontology at the Museum of Comparative Zoology. He was even offered a position as Research Professor at the Museum, but he declined the offer — at the last minute in the Cunard building in Liverpool — deciding to remain at Newcastle. He was also elected a Fellow of the Royal Society (FRS) in 1952, and in 1957 was a founder-member of the Palaeontological Association, founded as a breakaway from the Geological Society of London. He was its President from 1966–8.

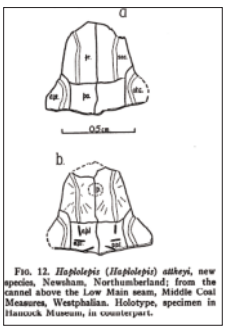


FIG. 12. *Haplolepis* (*Haplolepis*) *attheyi*, new species, Newsham, Northumberland; from the cannel above the Low Main seam, Middle Coal Measures, Westphalian. Holotype, specimen in Hancock Museum, in counterpart.

*Figure 73 A figure from Westoll's 1944 monograph: '*The Haplolepidae, a New Family of late Carboniferous Bony Fishes: a Study in Taxonomy and Evolution'. Bull AMNH ***83***. *New York; courtesy American Museum of Natural History).*

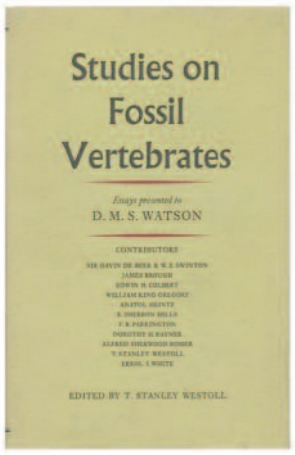


Figure 74 Front cover of Westroll's (ed) Festschrift *to D.M.S. Watson (1958) (author scan).*

Westoll edited a *Festschrift* for his former teacher and research colleague D. M. S. Watson in 1958, in which he contributed a paper on the evolution of the pelvic and pectoral fins in jawed vertebrates (Fig. 74). In 1959 he was invited to Melbourne to take part in a symposium celebrating the centenary of Darwin's *On the Origin of Species*. He made the occasion into a round-the-world trip, going via Harvard, San Francisco (where he met C. S. Forester and was given a signed copy of a Hornblower novel), Hawaii (where he witnessed an eruption of Kilawea), Fiji and New Zealand, returning via Indonesia. He boasted that it took him only 79 days, one less than Phileas Fogg.

In August 1966 the Royal Society became aware of plans by the MoD and the BBC to develop bases on Aldabra atoll in the Seychelles, part of the British Indian Ocean Territory. The United States Government was worried about Soviet expansion in the Indian Ocean and also wanted to establish a base on Aldabra. The Royal Society, however, was anxious to protect the unique habitat of the atoll and therefore sent Dr D. R. Stoddart of the Department of Geography at Cambridge to accompany an MoD/BBC expedition to Aldabra in September 1966. Stoddart's report led to a scientific expedition to the atoll in 1967 and set up the Aldabra Research Committee to co-ordinate operations, on which Westoll accepted the position of Chairman, hoping that he might acquire specimens of Latimeria (coelacanth) from the waters off the nearby Comores Islands to the south-west. Westoll was also awarded the Murchison Medal by the Geological Society that year.

The Aldabra Research Committee first met in February 1968 and in September Westoll and Stoddart visited Aldabra and the Seychelles aboard the converted Hull trawler *Manihine* (Fig. 75). On the voyage Stoddart recalls Westoll "with his gammy leg heroically struggling below decks with a glass carboy of formaldehyde that had broken loose in a storm, while the rest of us were tied to our bunks". The MoD plans were subsequently dropped but the Royal Society went on to set up a research station on Aldabra, which it manned until March 1980, after which control was passed to the, now independent, Seychelles. Westroll retired from the Committee in 1977.

During this period, Westoll was also busy building the Geology Department at Newcastle. He had a staff of three when he took over in 1948, which had increased to 12 by the mid-1960s. Much of his time was spent on administration, but his palaeontological and anatomical work was carried on by his students. He began to publish extensively on stratigraphy and sedimentology, particularly on the Silurian/Devonian boundary, and he made Newcastle a centre of Carboniferous and coal studies. He was President of the Geological Society of London 1972–4. In 1976 the Linnean Society of London held a symposium on 'Problems in Vertebrate Evolution' in his honour, resulting in his own *Festschrift* and the award of the Linnean Medal (Zoology) the following year (Fig. 76). Westoll was also awarded an LLD by the University of Aberdeen in 1977 and also received the Clough Medal from the Edinburgh Geological Society. He continued as Leverhume Emeritus Research Fellow and Chairman of Convocation at Newcastle for ten years. During his retirement he was unfortunate enough to see the break-up of the Department of Geology at Newcastle as part of the 'Earth Sciences Review', something he considered an act of vandalism.

Stanley Westoll was a gregarious man, full of anecdotes and stories. An excellent teacher and lecturer, he often taught without notes, reproducing world stratigraphic sequences from memory at a speed his students could not keep up with. He died in Newcastle on 19 September 1995. He will be remembered as an outstanding palaeontologist, stratigrapher and world authority on fossil fish. His son, Neil, graduated with a First-class Honours degree and PhD in Geology at Edinburgh and now works in mineral exploration in Ontario, Canada.

Figure 75 The research and survey vessel Manihine *(© Fleetwood Maritime Heritage Trust. www.fleetwood-fishing-industry.co.uk).*
Figure 76 The Linnean Medal (Wikipedia, Public Domain).

The Suture on a Shoestring continues: Severnside goes to Gaspé, Quebec Province, Canada, 14–21 September 2012

(led by Prof. Brian Williams and Prof. Ken Higgs)

Lexy Cruikshank, Linda Fowler, Janet Hiscott, Lyn Relph, Muriel Rogers, Gill Toney and Tony Wallbank

Introduction

Already in Severnside's 'Suture on a Shoestring' series we had organised trips to Northern Norway, Southern Norway, Scotland, the Isle of Man, Southwest Ireland and Newfoundland. Then, in September 2012, we headed off across the Atlantic again for the next episode of Iapetus suture exploration under the guidance of Professors Brian Williams (Aberdeen) and Ken Higgs (Cork). Our destination was the Gaspé Peninsula, that finger of land just south of the St Lawrence River and to the north of Canada's Maritime Provinces. We flew in to Halifax, Nova Scotia, on September 13th and drove, via an overnight stop in Moncton, New Brunswick, to our rendezvous with our leaders in Carleton-sur-Mer on the north shore of Chaleur Bay.

The Gaspé Peninsula is made up of rocks trending approximately E–W. These can be related to the Taconic (Cambrian to late Ordovician) and the Acadian (Silurian and Devonian) stages of the Caledonian Orogeny and to the Alleghanian/Appalachian (= European Variscan) Orogeny. In the north lie the Cambro-Ordovician rocks of the Humber and Dunnage terranes, Laurentian and oceanic crust respectively, which meet along the Baie Verte-Brompton line that marks the Iapetus suture during the Taconic phase. Farther south are Palaeozoic rocks (and a little bit of Precambrian) affected by the Taconic and Alleghanian orogenies; this also created a fabric with major folds trending E–W. To the south, Chaleur Bay lies in a Carboniferous palaeovalley. This field excursion gave us an excellent insight into the sedimentary processes associated with orogenies. Our route took us around the peninsula in an anticlockwise direction — based successively at Carlton-sur-Mer, Percé and Gaspé Town — and then making a brief visit to the south shore of the St Lawrence River before returning south across the Chic-Choc Mountains and making our way back to Halifax via the Joggins World Heritage Site. A day to spare at the end enabled some of us to explore intrusive igneous rocks of the Meguma Terrane, also part of the Appalachian orogenic belt.

South Gaspé Peninsula

Our first two-day stop on the south side of the Gaspé Peninsula enabled us to visit the Devonian fossil localities and exhibits at the Parc National de Miguasha, as well as other Palaeozoic exposures to the east.

Saturday 15 September: Parc National de Miguasha

Muriel Rogers

We were welcomed into the museum and introduced to three people, France and Olivier, who are PhD students, and Jason Willetts, the fossil *preparateur*. This area of the coast is a UNESCO World Heritage Site and possibly the most productive area for Devonian fish fossils in the world. Between 400 and 500 fossils are found each summer. *[LF: See the excellent Miguasha website* http://www.sepaq.com/pq/mig/index.dot?language_id=1 *for more details]*.

Figure 1 Miguasha foreshore. The low cliffs are made up of the Upper Devonian Fleurant and Escuminac Fms. An exposure of the Lower Carboniferous Bonaventure Fm forms the 'Hugh Miller cliffs' farther up the hillside in the middle distance (photo by L. Fowler).

The field locality was along the foreshore below the National Park centre (Fig. 1). The Lower Carboniferous Bonaventure Formation (hereafter Fm) is a terrestrial red bed succession, deposited in a semi-arid palaeoclimate, and we could clearly see the red beds above us in the hillside. The facies can be grouped into three associations — conglomeratic, sandstone and mudstone dominated. The megasequences are attributed to alluvial fan progradation due to tectonic rejuvenation. Varied alluvial environments are represented. Alluvial fans formed on steep slopes adjacent to fault scarps and are dominated by conglomerate deposits. Lateral and downslope coalescence of the fans into a braid plain is shown by the transition from conglomeratic to sandstone. Distally the braid plain is represented by transition into deposits of mudstone-dominated association. Chaleur Bay is believed to be an exhumed Carboniferous palaeovalley with axial drainage to the east.

The next two formations we looked at were the Upper Devonian Escuminac and Fleurant Fms. The Fleurant is the older formation. This would have been a high-energy braided river. The formation records times of high energy interspersed by low energy. The Fleurant Fm is a bimodal, clast-supported conglomerate, the clasts being of very varied sizes — with imbricate structures dipping upstream. During high-energy periods, everything moved

© OUGS ISSN 0143-9472

Figure 2 The Fleurant Fm showing bar-edge sand wedges (photo by M. Rogers).

downstream, but during low-energy periods the sand settled out either on the bar top or draping the edges producing bar top, or bar edge, sand wedges (Fig. 2).

The Escuminac Formation sits above this last formation, the sandstone drapes the edges of the Fleurant Formation but nowhere is there evidence of the conglomerate being reworked into the sandstone. Discussion continues as to whether it is an unconformity, disconformity or hiatus and of what duration? The Escuminac Formation is 117m thick and forms steep cliffs up to 30m high along the coast. Fossils are found throughout. Fine laminations at the base change upwards to thicker sandstone beds. There are five different lithofacies associations — mainly shales and calcareous siltstones/sandstones. There are regular deposits of dark organic layers and light layers of quartz/calcite. The beds have been numbered and the fish fossils have been found starting at Bed 8 and above, but not below (Figs 3 and 4). We didn't find any fish, but there were oodles of fish 'pooh'.

Figure 3 The 2012 fossil excavation site (photo by L. Fowler).

Figure 4 Olivier Matton explaining the seasonal excavation programme (photo by L. Fowler).

As we worked our way along the shore we came to the start of the Bonaventure Fm, an area of layered, light-coloured sandstone and dark finely laminated mudstone, dipping *c.* 10˚. This would have been laid down by turbidites, but here we have another debate — turbidites are associated with deep sea and lacustrine settings, but among the flute marks, ripple and cross-bedding examples, both current and wave, were indications of a relatively shallow water regime.

After lunch we were taken downstairs in the museum to see the fossil collection room full of drawers and drawers of fossils, and the fossil preparation room where Jason showed us his equipment — microscope, lights and dust extractor attached, and the etching tools he uses to painstakingly remove the rock to expose the fine delicate microscopic features of the fossils. It takes days to clear a very small area. He showed us work in progress, one of which was a very rare fish (Figs 5, *below*, and 6, *opposite*). The fossils found at Miguasha cover all the fish types, but the main ones are *Agnathans*, *Placoderms* and *Acanthodians*.

Sunday 16 September: Black Cove, Yacta Point & Pirate Cove
Tony Wallbank

Black Cape looked its name as we drove out to sea along a flimsy looking jetty beside the Marina at New Richmond. It provided an excellent, if blustery, overview of this marine Silurian section, considered one of the best in North America (Fig. 7, *opposite*).

Figure 5 Jason Willetts explains the preparation process (photo by L. Fowler).

Figure 6 A fossil fish in course of preparation (photo by L. Fowler).

After a short introduction from Brian and Jason (from Miguasha) we drove around to the beach, about halfway along the section, put on our waterproofs and started looking for fossils. We spotted stromatoporoids first, sitting in slabs of rock, sometimes with corals though more often on their own. Corals were abundant, colonial and single varieties, including a chain coral recognised by one member as similar to those of Wenlockian age found in Shropshire (Fig. 8).

We also found corals in broken slabs fallen from the cliffs, although more came from the beach as weathered-out specimens (Figs 9 and 10). Brachiopods were present in smaller numbers, including Orthids and other types; we found one Nautilus shell and plenty of stromatoporoids.

The steeply dipping strata varied from soft to hard, mudstones, limestones and sandstones (Fig. 11, *overleaf*).

We could not quite reach Black Cape itself, as the tide was too high, although we were already into the beginning of volcanic strata. There was some evidence of bentonites and eroded harder ribs showed where softer beds had been scoured out by wave action on the windward side (Fig. 12, *overleaf*). Closer to the point more of the beach pebbles were volcanic, some containing large feldspar crystals and one showing zeolites and flow-banded feldspars.

Figure 8 Chain coral at Black Cape (photo by T. Wallbank).

Figure 9 Fragments of colonial corals at Black Cape (photo by T. Wallbank).

Figure 10 Coral at Black Cape (photo by T. Wallbank).

Figure 7 Part of the Silurian section at Black Cape seen from jetty (photo by T. Wallbank).

Figure 11 Strata at Black Cape (photo by T. Wallbank).

Figure 12 Ribs showing scouring at Black Cape (photo by T. Wallbank).

We returned to the museum for lunch, where we hoped that Ken could help us identify the brachiopods we had found, although a poster on the wall was very helpful too. We had another chance to spend in the museum shop, where foularde tubulaire were all the rage.

The afternoon was no less blustery, though sunny. We descended a track a short distance east of the museum site to find the Bonaventure Fm, 'red beds' of Mississippian age, at Yacta Point (Fig. 13). Here they are exposed at beach level, showing that there must be a fault between here and the museum where the beds were tens of metres higher up, lying unconformably on the Escuminac Fm.

These red beds are the youngest bedrock in the district: they outcrop over a wide area, and comprise conglomerates, mudstones and sandstones. We found no fossils, but we did see evidence of channels, splay deposits and a floodplain sequence showing cycles of fluvial deposits with long arid periods (Figs 14 and 15). Brian explained that the dry periods with, of course, no sedimentation could last for 10–100 thousand years, as testified to by the extensive development of calcrete palaeosols.

Figure 13 (right) Brian explaining the Bonaventure Fm at Yacta Point (photo by T. Wallbank).

Figure 14 (below) Floodplain sequence with calcrete layer halfway up at Yacta Point (photo by T. Wallbank).

Figure 15 Calcrete at Yacta Point (photo by T. Wallbank).

Figure 16 Miguasha Road section (photo by T. Wallbank).

A short distance to the east we stopped at a cutting on Miguasha Road (Fig. 16). The exposure here was of conglomerate, with a wide range of clast sizes, though dominated by gravel. It was *c.* 20m thick, and showed flow mostly from west to east.

Our final stop of the day was near Pirate Cove where the Pirate Cove Fm, 500m thick, could be seen with Fleurant conglomerate and Escuminac Fm (Fig. 17).

Carlton to Percé

Monday 17 September: South Gaspé from Carleton to Percé

Gill Toney

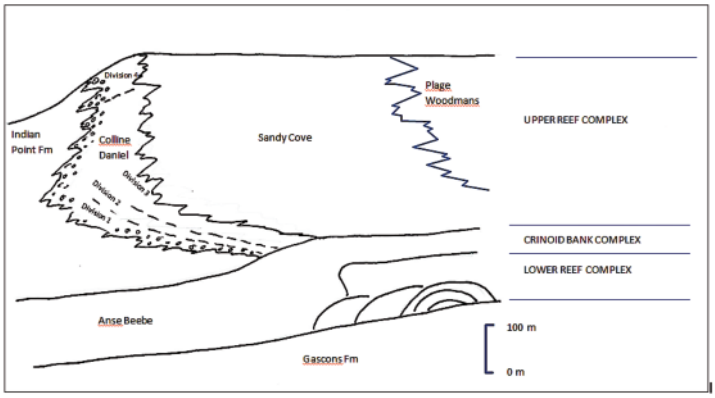
Leaving Carleton-sur-Mer we headed east along the coast road, traversing the Lower Carboniferous Bonaventure Fm conglomerate, which sits unconformably on Silurian (West Point) and Precambrian (Pabos Mills) rocks.

Our first stop was at Pointe du Sud-Ouest (West Point; Fig. 18), where the rocks are part of the upper section of the West Point Fm, a carbonate build-up that has been divided into a lower reef complex, a middle crinoidal bank complex and an upper reef complex. The upper reef complex is further divided into three laterally equivalent units: the Colline Daniel unit (*see below*), and the Sandy Cove and Plage Woodmans units, which represent the back reef. There is also lateral continuity into the Indian Point Fm, which represents the forereef (Fig. 19). A walk to the lighthouse brought us to the massive limestone exposure of the Colline-Daniel unit, which lies above the Anse Beebe unit and offshore of the backreef units, and represents the progradation of the reef margin. Although the Colline-Daniel unit is subdivided into four divisions, only the first three are visible at the lighthouse cliffs. Division 1 (the base of the Colline Daniel unit) comprises 26m of detrital facies of biogenic conglomerate, crinoid rudstone and 'Cladopora' boundstone topped by a 6m debris flow;

Figure 17 Pirate Cove overview (photo by T. Wallbank).

Figure 18 The Silurian carbonate exposure at Pointe du Sud-Ouest (photo by L. Fowler).

Figure 19 Relationships between the units of the West Point carbonate build up (modified by Linda Fowler from Bourque, P. A., and Lachambre, G. 1980 'Stratigraphie du Silurien et du Dévonien basal du Sud de la Gaspésie: Québec'. Department of Energy and Resources Special Paper E5-30).



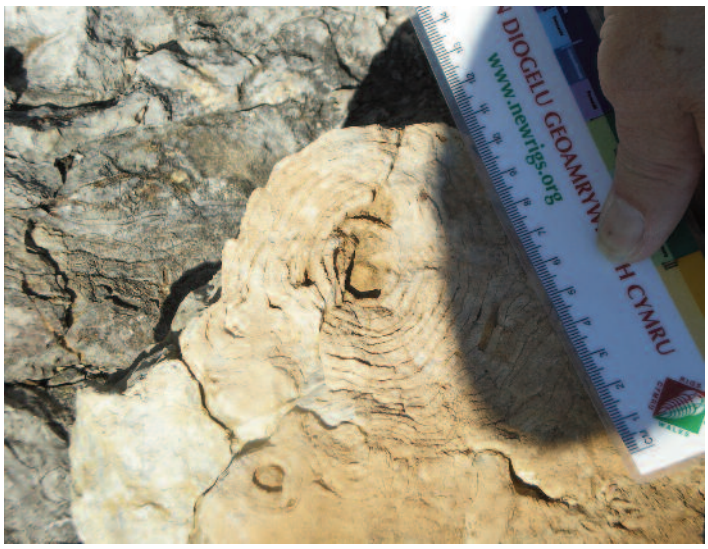


Figure 20 Stromatoporoids in the micritic limestone of the Colline Daniel Unit of the West Point Fm at Pointe du Sud-Ouest (photo by G. Toney).

Division 2 comprises a 10m algal-bound unit of spongiostromate-renalcid boundstone and tabular coral bioherms; and Division 3, easily accessible at the top of the cliffs, comprised a 30.5m unit of laminar to tabular stromatoporoid-spongiostromate framestone. Here we found crinoids, sponges, tabular corals and stromatoporoids bound in a micritic limestone (Fig. 20). This section of the Colline-Daniel unit was deposited in a high-energy environment with the strata now dipping deeply to the south.

Farther along the coast we stopped at Pabos Mills, where the rocks are Precambrian metamorphics, and have been dated from volcanic ash incorporated in the rocks. This area had a thriving fishing industry between 1730 and 1758, before the demand for timber saw a change to logging and the development of the site as a timber mill. However, by the turn of the 20th century over harvesting led to a timber shortage with the subsequent decline and closure of the mill. Part of Pabos Mills has been an archaeological site since 1975.

Across the railway line on the beach we examined an exposure of highly deformed metamorphic rock that contained conglomerate, basalt, greenschist and greywacke sediments. It was difficult to work out what events had occurred here, but it had apparently undergone three stages of deformation during the closing of the Iapetus Ocean (510–430Ma), having been deformed by the Taconic, Acadian and Alleghanian events.

There were *mélange* zone rims, extension joints, evidence of both brittle and ductile deformation (polyphase deformation) and crenulation cleavage (Fig. 21). We also observed sedimentary clasts cut by later extensional joints.

Is this exposure an enigmatic exotic terrane? There are several lines of thought. The exposure could originally have been part of Avalonia, formed before the opening of Iapetus Ocean, with the rift being either Lower Cambrian or Pre-Cambrian in age. If so, then this terrane could have been displaced either from the north, or preserved behind the leading edge of Avalonia, or even as a microplate from the south.

From Pabos Mills we continued on to Percé, where we had good views of the Percé Rock (Fig. 22), which gives the town its name, and of Bonaventure Island. We spent the night at 'Au Pic de l'Aurore', which lived up to its name at sunrise the next morning when the eponymous red bed cliff caught the early morning sunshine (Fig. 23, *opposite*).

Figure 21 (below, left) Crenulation cleavage in the Precambrian exposure at Pabos Mills (photo by G. Toney).

Figure 22 (below, right) Percé Rock (photo by L. Fowler).

Figure 23 Pic de l'Aurore, Percé (photo by L. Fowler).

South-east Gaspé

Tuesday 18 September: Percé town to Gaspé City

Linda Fowler

After an initial stop on the Mont Joli foreshore just north of Percé town itself, a shorter drive took us through the Upper Carboniferous and Middle/Lower Devonian Malbaie and Battery Point Fms on the southern shore of Gaspé Bay.

Mont Joli lies opposite Percé Rock: here we saw a classic sequence of relatively rare Lower Devonian carbonate turbidites of the Mont Joli Fm. The rocks have been tilted almost vertical (Fig. 24) and there are some excellent examples of 'way-up' sedimentary structures (Fig. 25, *overleaf*).

Leaving Percé we drove north along the coast to Cannes de Roche, where a convenient bend in the coastline exposes the fluvial Malbaie Fm in a dip section to the south and a strike section to the north of the access point (Fig. 26, *overleaf*). Chronologically this is equivalent to the Lower Carboniferous Bonaventure Fm red beds and the section here shows valley-side fan deposits of the Lower Member, red megabreccia, overlain by red mudrocks of the Middle Member. The Upper Member, which is buff coloured and includes plant material, was deposited by the braided river flowing down the centre of the valley. Evidence of subaerial/fluvial environment observed included plant debris up to log size, some impressive beaconites burrows (Fig. 27, *overleaf*), calcrete nodules, trough cross sets (Fig. 28, *overleaf*) showing that the main trunk river flowed to the south-south-east, and linguoidal ripples.

Figure 24 Sub-vertical beds of the Indian Point Fm exposed in cliffs at Mont Joli, looking towards Percé Rock (photo by L. Fowler).

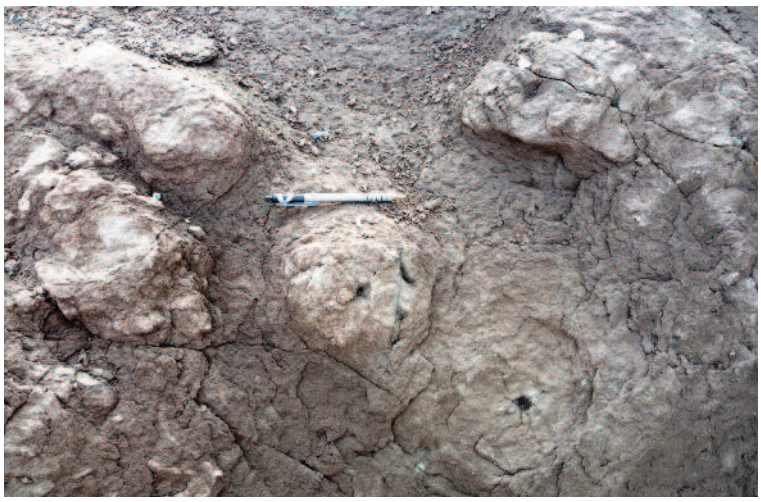


Figure 25 (top left) Way-up structures (ball and flame) in a fallen block of rock at Mont Joli (photo by L. Fowler).

Figure 26 (below) Strike section of the Malbaie Fm looking north at Cannes de Roche. The beds dip steeply seaward and are cut by valleys producing V-shapped outcrop patterns (photo by L. Fowler).

Figure 27 (top right) Beaconites burrows, Malbaie Fm, Cannes de Roche (photo by L. Fowler).

Figure 28 (right) Trough cross-sets in the braided river deposits of the Upper Malbaie Fm, Ken Higgs for scale (photo by L. Fowler).

The Middle Devonian Malbaie Fm is at the top of a 5km thick clastic wedge. We next moved north up the coast to Tête d'Indien (Fig. 29), and back in time, to the Lower Devonian at the base of this wedge. The York River Sandstone at Tête d'Indien is a texturally and compositionally immature shallow marine rock. It is thinly laminated (Fig. 30) and displays strong parting lineation (primary current lineation) where the individual sand grains are aligned (Fig. 31).

Cross-stratified conglomerates in the formation showed as paler and darker bands: these result from alternating bands with more and less calcite cement. The cement is white and makes the bands with more cement paler in colour (Fig. 32).

The final location at St Georges de Malbaie enabled us to see the Fort Prevel Member in the upper part of the Battery Point Fm, a preview of the following day. However, the tide was coming in and we were unable to do it justice. It is made up of a series of unconfined flows representing sheet floods. This is the Battery Point Fm 'Association 2' (*see below*).

We spent the next two nights at the shore side Chalets au Bout du Monde near Gaspé City, which enabled us to spend the intervening day exploring the Parc National de Canada Forillon.

North Gaspé

Wednesday 19 September: The Forillon Peninsula

Lyn Relph

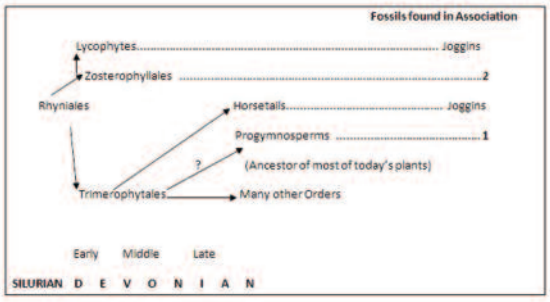
We began our trip on the north shore of Gaspé Bay (the south shore of the Forillon Peninsula) in very wet and windy weather, which was to shape the rest of the day. We started where we left off on Tuesday, in the Battery Point Fm at Cap-aux-Os. The Cap-aux-Os Member is the middle of the three members that make up this formation. The member above is the Fort Prevel Member seen on Tuesday, and the one below, which forms the base of the formation, is the Petit Gaspé Member.

Figure 29 (top left) The rock profile that gives Tête d'Indien its name (photo by L. Fowler).

Figure 30 (top right) Thinly laminated York River Sandstone at Tête d'Indien (photo by L. Fowler).

Figure 31 (bottom left) Parting lineation (parallel to pen) on a bedding plane of the York River Sandstone, Tête d'Indien (photo by L. Fowler).

Figure 32 (bottom right) Cement banding in cross-stratified conglomerate in the York River Sandstone (photo by L. Fowler).



The world famous Lower to early Mid-Devonian terrestrial sediments of the Battery Point Fm are 2.3km thick and were deposited in a basin that drained west to the north-west through a distal braided plain and meandering fluvial system. The sediments coarsen upwards as water levels decreased and energy increased. There are three 'Associations':

Association 3 = sand-filled fluvial and coarse-grained
Association 2 = mudstones from splays and swamps
Association 1 = meandering river channel sandstones and bars

Within these sediments there are marine incursions with brachiopods and numerous horizons containing palaeolsoils and plant fossils. The very early plant fossils are like those from Scotland found in the Rhynie Chert: simple stems that branch dichotomously and terminate in spore bodies. These contained two evolutionary lines that later developed into the *Lycopsids* and the *Progymnosperms* (spore bearing). The two lines are linked to different environments: the growing conditions and the conditions of deposition (Fig. 33).

Trimerophytes are linked to Association 1. They are found on channel margins and muds on top of bars, and are likely to have grown upstream in a more arid environment, then been washed down in times of flood to where they were deposited.

Figure 33 (top left) Orders of land plants discussed in the text (L. Relph).
Figure 34 (top right) Fragmented plant remains in the Cap aux Os Member of the Battery Point Fm (photo by L. Fowler).
Figure 35 (below) Because of the wind-held tide we were unable to access the next stop (photo by L. Fowler).

Zosterophylls (with a star-shaped vascular system) are linked to Association 2. They are found in flood areas, back marshes and ponds, possibly the environments in which they grew.

Photocytes and *Spogiophytes* are linked to Association 3. They are found in river channels having been washed down from elsewhere.

Photocytes are thought to be large fungi (the ancestry of fungi is uncertain). The remains of the stalks we saw were about a meter tall and about 400mm in diameter.

The plant remains we saw were very fragmented — we only found rare dichotomous branch and leaf fragments (Fig. 34). There was also some evidence of soils having formed.

We were unable to access the next stop to look at river bar sediments because the wind was so strong that it held the tide in the bay (Fig. 35).

Figure 36 The Griffon Cove River Fm in a quarry on Route 197 (photo by L. Relph).

Our next location was at Petit Gaspé: here we were at the base of the Battery Point Fm in the Petit Gaspé Member. These sediments were laid down by a meandering river system with tabular cross-bedded bars and rippled tops. The edges of the river channels are marked by cross-channel bars that built out into the channel. In the early part of deposition of this member the river drainage pattern changed in response to the Acadian Orogeny. The 1.6km thick delta of the York River Fm lies beneath this.

We moved on to a road cutting in Route 197, which cuts across the peninsula. This cutting exposed the limestones and calcareous muds of the Roncelles Fm. This sequence shallows and youngs uphill, so we worked our way downhill and down sequence. The deposits suggest shallow marine conditions in a continental shelf environment subject to carbonate precipitation and terrigenous influx. This was preceded by a transgressive phase and rise in sea level in the Lower Devonian. A thick sequence of bedded limestone contained abundant fossils in discreet horizons. An excellent example of the brachiopod *Leptaena* was found, as were numerous corals. Thin lenses of shell debris were also present. Below the limestone is the quarry where we found the Griffon Cove River Fm (GCR Fm). This contained lenses with pebble and cobble petromictic conglomerates (Fig. 36). The top of the GCR Fm was interbedded with fine-grained laminated shales containing small very angular clasts. Those in the GCR Fm were much larger and said to represent a flysch sequence indicating a deep-sea turbidite.

Across the road we went down the bank to the river looking for the angular unconformity of the Ordovician with the Silurian-Devonian sequence above, a junction ascribed to the Taconic Orogeny. The thin-bedded sandstones were deformed and dipped steeply, but despite several of us splashing around in the river we did not find the contact. Interestingly in this potential reservoir rock, on hammering the limestone, we detected the smell of oil.

The drive back around the peninsula via Cap des Rosiers afforded some stunning sea- and cloud-scapes (Fig. 37).

Figure 37 Le Vieux Cap Gaspé from Cap des Rosiers (photo by L. Relph).

Thursday 20 September: Gaspé Town to St Anne des Monts
Janet Hiscott

After the bad weather of the previous day, Thursday dawned bright and sunny. As we took a last look out across the bay from Les Chalets au Bout du Monde, a bald eagle flew in and fished for his breakfast off the point. Leaving the chalets, we headed north-west from Gaspé City to Murdochville Copper Mines, situated inland among the hills. This was a pleasant drive over the Acadian fold belt, enabling us to enjoy the beautiful autumn colours. *En route*, stopping to admire the view and prompted by the recent discovery of oil and gas in the Devonian of Gaspé, Brian delivered an impromptu lecture on the formation of oil and gas, how there need to be 'five magic ingredients': the correct source rocks, heat within the correct range (not too hot, not too cold), a reservoir with permeability and porosity qualities, the presence of an impermeable seal and a structural trap (either a fault or a fold or a combination of both).

We knew that the mine had closed down in 1999, but arriving in Murdochville we searched unsuccessfully for the Interpretation Centre, eventually discovering that it had burnt down in January! However, later in the day at Mont Louis we found huge blocks from the mine used as coast armour, which displayed much mineralisation and all easily accessible. We identified azurite, malachite, bornite, chalcopyrite and iron pyrite (Fig. 38), galena, copper pyrite, sphalerite and barytes; later X-ray diffraction analysis showed some unusual pale blue crystals, which we collected and which turned out to be molybdenite *[Ed. — see article by Lyn Relph, page 89]*.

At Mont Louis, on the north coast of the Gaspé Peninsula, we were in the Humber Zone and looking at the Cloridorme Fm.

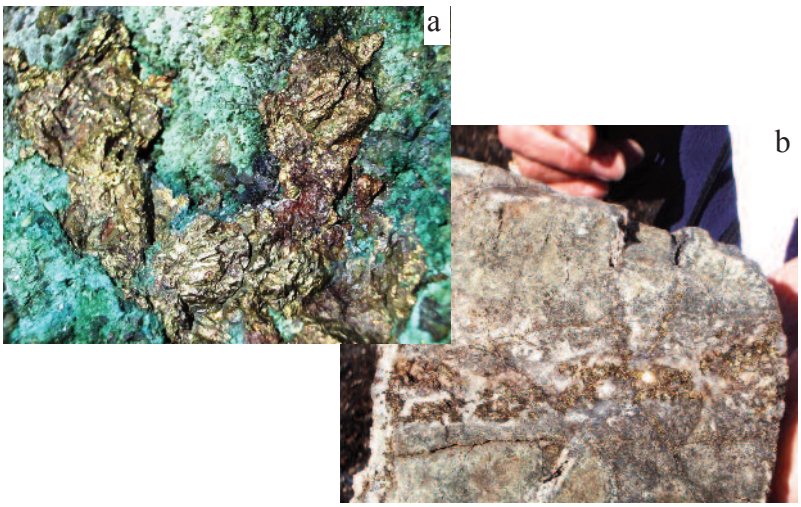


Figure 38 (a) Chalcopyrite and (b) iron pyrites in rock armour at Mont Louis, assumed to be from Murdochville (photos by L. Cruikshank).

These are deep sea sediments deposited as turbidites in an east-west basin on the southern edge of Laurentia during the Middle to Upper Ordovician. Some of the sandier packets can be traced laterally for 25km and individual beds for up to 7km. The rocks have been highly deformed by the Acadian, Taconic and Variscan orogenies (Figs 39, and 40 and 41, *opposite*). We examined beds ranging from mudrocks to sandy units containing grooves, ripples and rhythmic sequences. These can be compared with the turbidite reservoirs of the North Sea, which are interpreted as representing the distal part of a fan and resulted from a plume underplating northern Scotland and causing uplift. The erosional products from the resulting mountains flowed as turbidites into the sea and became today's North Sea oil reservoirs.

Figure 39 Folds on the foreshore seaward of the breakwater at Mont Louis (photo by J. Hiscott).

Figure 40 (left) West-plunging syncline on the foreshore inside the breakwater at Mont Louis (photo by L. Fowler).
Figure 41 (middle) Load casts in the Cloridorme Fm at Mont Louis (photo by L. Fowler).
Figure 42 (bottom left) The Cap Chat mélange *exposure at Marsoui (photo by L. Fowler).*
Figure 43 (bottom right) Close-ups of the Cap Chat mélange *(a) fossil fragments including crinoid ossicles (photo by LC) and (b) burrows with coprolites (photos by J. Hiscott).*

Moving west, we drove along with an extensive wave-cut platform to our right and high cliffs of turbidites to our left. At Marsoui we examined the Cap Chat Fm (Fig. 42). This is an olistostrome and is a chaotic *mélange* of radiolarian chert that has been intensively burrowed. Many photos were taken of these burrows and their contents of faecal pellets (Fig. 43). The non-geologists among us were highly amused at this activity! *[LF: Particularly in the context of the name, which to English ears sounded as though it had coprolitic overtones.]*

At St Anne des Monts, a roadside exposure of the Tourelle Fm showed another Bouma sequence, again Ordovician (Arenig) in age (Figs 44 and 45, *overleaf*). The allochthon of which this is part formed of mixed sediment fans in a deep ocean basin as Iapetus Ocean closed, but the rocks here are more proximal than the sediments we had seen in the Cloridorme Fm.

Figure 44 Tourelle Fm near St Anne des Monts (photo by L. Fowler).

Friday 21 September: St Anne des Monts to Mirimichi
Linda Fowler

Leaderless for a day, as Brian and Ken had set off early to pay a second visit to Miguasha *en route*, we headed south down the main route across the Gaspé Peninsula and on to our overnight stop at Mirimichi in New Brunswick.

Figure 45 The Tourelle Fm (here dipping 70° W) exhibited T_C, T_D and T_E Bouma units (photo by L. Fowler).

This was an opportunity to review the E–W trend of the terranes across the peninsula, as we began by crossing the Taconic Lower Ordovician rocks of the Humber and Dunnage terranes (Fig. 46) before crossing onto the Silurian and Devonian rocks of the Acadian chain. Some 40km south of the St Lawrence shore we reached a point on the Baie Verte–Brompton line (the suture between Laurentia (the Humber terrane) and the Palaeozoic ocean (Dunnage terrane) where ophiolite material occurs in nappes (Fig. 47). Uplift and erosion of the ophiolite material produced olistostrome melange and onlapping flysch deposits.

Brian and Ken planned to catch an overnight flight from Halifax on Saturday evening so we enjoyed a slightly early 'last-night group meal' at their hotel in Mirimichi on Friday evening before continuing our journey south the next day. The torrential rain we drove through cleared somewhat by the time we reached Joggins.

Figure 46 (above) The road south switchbacks across the E–W trending ridges of the Chic-Choc Mountains (photo by L. Fowler).

Figure 47 (below) An exposure of ophiolite on a hilltop south of Mont Albert has weathered to a typical reddish-brown colour (photo by L. Fowler).

Figure 48 (left) The foreshore at Joggins on the south side of the Bay of Fundy (photo by L. Fowler).

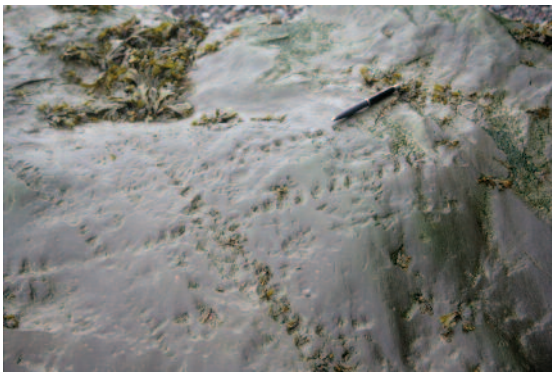


Figure 49 (middle) Giant millipede tracks at Joggins, Nova Scotia (photo by L. Relph).

Figure 50 (bottom) Plant stumps preserved in life position in the Joggins cliffs (photo by L. Fowler).

Nova Scotia

Saturday 22 September: Joggins, Nova Scotia

Lyn Relph

Joggins is a UNESCO World Heritage Site on the Bay of Fundy. It is renowned for extreme weather (we got the wet windy version) and a big tidal range (Fig. 48). The site consists of 15km of accessible coastal cliffs with 34 coarsening-up terrestrial sedimentary cycles of Pennsylvanian age (Upper Coal Measures in old money). It is important because terrestrial sedimentary deposits are relatively rare and Joggins preserves a long, *in situ*, detailed lowland ecosystem.

The depositional cycles were controlled by ice caps, which waxed and waned thus changing the sea level. The deep-water sediments are black shale; these coarsen upwards as the water depth decreases, and contain *Goniatite* fossils. They are capped by thick massive sandstones and brine coal. The sandstones were deposited as bar tops and the coal in swamps.

The earliest reptile was found here at Coal Mead Point in the Westphalia A sequence. The first land snails were also found at Joggins. The top predators were the amphibians, of which there were several. A fossil was found in a rotted 'tree' stump, possibly where it lived. We also saw some magnificent giant millipede tracks (a meter or so long) (Fig. 49); and it would appear from the crossing tracks that they were quite common. Large club mosses, which could grow to 40m high, *Lepidodendrons* and *Sigillaria*, took the role of trees in today's woodland (Fig. 50). These plants were mainly responsible for producing the coal we mine today. We also saw some *Calamites* (horsetails) on fallen blocks by the steps, but the rooted plants had been obscured by a recent rock fall. Delicate, ferny 'seed fern' leaves were also found, which could have been from either trees or climbing plants.

Joggins is part of the same system as Brymbo in North Wales, to which it was joined before the opening of the Atlantic Ocean.

This was mainly a travelling day, so the Joggins visit was quite short. We then travelled south to look at a section of Triassic coast, but time was running out and the weather was again very wet and windy so we just stopped for a quick look round the Fundy Geological Museum before heading back to Halifax for our leaders to catch their plane home.

a

c

b

d

Sunday 23 September: Peggy's Cove and the Meguma terrane
Linda Fowler

The rest of us still had a day before our overnight flights back to the UK and some decided to explore the granite intrusion, part of the Meguma terrane, at Peggy's Cove.

We arrived there in early morning mist, but even so were impressed by the extent of the granite exposure between the small fishing/tourist village and its lighthouse (Fig. 51). Peggy's Cove — a Land's End, Giant's Causeway and John O'Groats type place — is reasonably low-key commercialisation of a place that is stunning in its own right. While the mist lifted we spent enjoyable time wandering over the granite exposure and finding the numerous xenoliths for which it is famed (Fig. 52).

Acknowledgements

Thanks go to Professor Brian Williams for checking the accuracy of this account, and to him and Professor Ken Higgs for their leadership; to the staff at Miguasha World Heritage Site for their help; and to Jan Ashton-Jones for organising car hire, and finding accommodation at the seven different locations the tour involved.

Figure 51 (top left) Peggy's Cove granite exposure (photo by L. Fowler).
Figure 52 (bottom left) Xenoliths in the granite at Peggy's Cove: (a) and (c) appear to be sedimentary material, perhaps incorporated by stoping; (b) and (d) appear to be mafic igneous material (Canadian 25¢ coin for scale is 24mm in diameter; photo by L. Fowler).

Book review

Pfiffner, O. Adrian 2014 *Geology of the Alps*. Oxford: Wiley Blackwell (ISBN 978-1-11870-813-2; 376pp; hardcover £85, paperback £42.50)

Everyone who has studied S339 has had an introduction to a portion of the Alps — the Western Alps — as an example of continental compression, with mountain-building through thrust tectonics, a variety of orogenic structures, hinterland, Inner Zone, Outer Zone, and foreland. This magisterial work by the Professor of Geology at the University of Bern since 1986 covers, naturally, the whole chain (including the Jura Mountains and the Alpine foreland to the north and south), and the whole history of the constituent rocks, "… starting with the pre-Triassic crystalline basement, followed by Paleozoic, Mesozoic and Cenozoic sedimentary sequences. The lithological description of the rock types is supplemented by a discussion of their paleogeographic and plate tectonic contexts" — to quote the publishers' description. The careful description of all the rock suites, both their deposition and their experience of the Variscan Orogeny, is one of the most interesting features of the book.

This analysis of pre-Alpine features means that the tectonic structure of the Alps does not appear until half way through the work, and the final sections cover the evolution of Alpine drainage patterns and the region's glacial history. It is stressed that convergence between the Adriatic (Apulian in S339) and European plates is still going on, with a variable uplift rate, especially high in the Penninic nappe system. As in the Southern Alps of New Zealand, this is balanced by erosion.

A notable feature is the profusion of superb illustrations: maps, cross-sections, diagrams, photographs, all extremely clearly produced and in full colour. References are given at the end of each chapter; many of the articles cited are in English, wherever the journals are produced.

This translation is of the second German edition, but is in effect a third edition: it includes more photographs and very considerably revised maps and figures, and also more on Alpine metamorphism; and in the section on the most recent history, data from Italy and France — all this added to the German second edition.

As it is so detailed, this is not an easy book to browse, but would be extremely rewarding for those going on Alpine field trips, and essential for serious students of this classic mountain chain. The paperback price seems remarkable for a volume with so much in it.

— Philip Clark BSc (Hons)

Book review

Harpp, Karen S., Mittelstaedt, Eric, d'Ozouville, Noémi, and Graham, David W. 2014 *The Galápagos; a Natural Laboratory for the Earth Sciences*. American Geophysical Union Geophysical Monograph 204. Oxford: Wiley Blackwell (ISBN: 978-1-118-85241-5; hardback, xv + 427pp; £100)

This weighty monograph contains 17 papers presented at a Chapman Conference at Galápagos in 2011. They cover volcanism, plate tectonics, biodiversity, hydrology, climate change and more.

Some observations: It would have been helpful to group the papers thematically. 'Galápagos' is a wide subject, and the order does not always seem logical. 'Natural laboratory' raises expectations. These pages are brim full of new ideas, but major hypotheses are assumed, not tested.

We learn much here about the tectonic setting, geochemistry and magmatism of Galápagos. These volcanic islands are formed on ridges near the Nazca–Cocos plate margin. Whereas Hawaii has intraplate hotspot volcanism, the Galápagos volcanism is on young oceanic lithosphere formed at the Galápagos Spreading Centre (GSC). Galápagos and Easter Island have mirror image geochemical anomalies, so the hotspots may originate on opposite sides of a common source. This could suggest a technique for mapping mantle structure. On volcanoes, Fernandina volcano sources mantle material from the Galápagos plume. Farther south, at Floreana, subduction zone oceanic crust is also present.

One paper identifies three stages of magmatism: a basaltic phase associated with cooling and crystallisation near the hotspot; a mid-phase of differentiated shallow sub-caldera sills associated with tholeiites; and late siliceous eruptions as the crystal mush solidifies. Might this model extend to the Palaeogene Volcanics of Scotland? Helium depletion at the GSC is intriguing. The contributors invoke plume shearing at the plate margin, but there are other explanations.

These islands are home to Darwin's finches, but the biodiversity papers seem weak, particularly on evolution and genetics. That number of species correlates to island age is interesting, as are the effects of Holocene sea level rise, but could insularity be used to advantage in testing the latest ideas in these fields?

Darwin observed that the islands are cool for their equatorial location. They obstruct the Equatorial undercurrent, contributing to a mass imbalance, which contributes to the trade winds. Longer-term, the Galápagos may contribute to climate change by weakening the El Niño Southern Oscillation (ENSO). Tsunami damage is increased by shelf resonance on the Galápagos platform. Perched aquifers provide scarce freshwater, but overexploitation can reduce surface runoff. Freshwater is also obtained from the basal aquifer inland, balancing human needs with agriculture.

This is a book for specialist libraries and researchers. The 'natural laboratory' subtitle made me wonder if more important work could be done here, testing Mantle plume, evolution and climate change models. The resulting book might interest a wider readership?

— Peter Blackett BSc Hons (Open)

Book Review

Thordarson, Thor, and Höskuldsson, Ármann 2014 *Iceland, Classic Geology in Europe 3* (2nd edn). Edinburgh: Dunedin Academic Press (ISBN 978-1-78046-021-5; paperback, 256pp; £24.99)

Iceland is one of the most physically dynamic countries on Earth. Between 2002, when the first edition of this book was published, and 2014 there have been four volcanic eruptions; not only reshaping the face of the land but having far-reaching affects on the rest of the world. Lovers of Iceland will welcome this new and updated edition. As the authors themselves say 'With a new publisher comes a new vision'.

In addition to revising the content, this book has beautiful photographs and clear colour diagrams, which support the text and make it a pleasure to read. The latest eruptions up to 2014 are described; the section on Heimay has been expanded and moved to a new location; and the Hrossaborg tuff cone near Askja has been included. GPS coordinates are given in text for the key locations; technical terms are kept to a minimum, and any that are used are in bold type and explained in a glossary; and there is a full bibliography.

The general introduction has a note on travel and weather, and is followed by an excellent overview of Icelandic geology, its global setting and the effects that volcanism and climate have had on settlers in Iceland. The book then describes the geology of specific areas by visiting the most popular localities that can be accessed using Highway 1 and taking an anti-clockwise direction of travel.

Each chapter has a local geological map, numbered to correspond with the locations of the excursions, which are then described. The book begins with the region from Snæfellsnes to Öræfajökull within easy reach of Reykjavík, and then continues with the Golden Circle and Hekla, followed by a short chapter on the Westmann Islands (Heimay). The southern part of Iceland covers Eyjafjallajökull, Mýrdalsjökull, Katla and the result of the jökulhlaups along the coast. The Laki fissures, Vatnajökull ice sheet and Skaftafell national park are all included. Travelling farther around Highway 1 the Eastern Fjords, Krafla, Mývatn, and the Skagi Peninsular are visited, ending with a trip into the interior highlands around Herðubreiðalindir, Asjka and Kverkfjöll.

This is a lovely pocket-sized guidebook with a wealth of geological detail on places to visit in Iceland and with clear information on specific sites and places of interest along the way. It would be a welcome and affordable addition to anyone's bookshelf.

— Eileen Fraser ex-OU GeoScience Tutor, BSc Hons (Open), Dip Earth Sci (Open), Dip Contemporary Sci (Open), FGS

East of Scotland OUGS Helmsdale Weekend field trip
(led by Nigel Trewin)

Jenny Allan, Anne Morton and Michael Perkins

Day 1: The Jurassic coast at Helmsdale

Michael Perkins

In contrast to the huge swathes of Lias found in England, the surface expression of the Jurassic in Scotland is a limited affair. However, one of the places where it does outcrop is a small fault-bounded sliver on the far north-east coast at Helmsdale in Sutherland (Fig. 1). Hoping to pass on some of its fascinating story, Prof. Nigel Trewin, author of several books on Scottish fossils, specialist in the Old Red Sandstone (ORS), and seasoned leader to this complex area, led an enthusiastic group of OUGS geologists on a varied weekend trip starting on Saturday 10 May 2014.

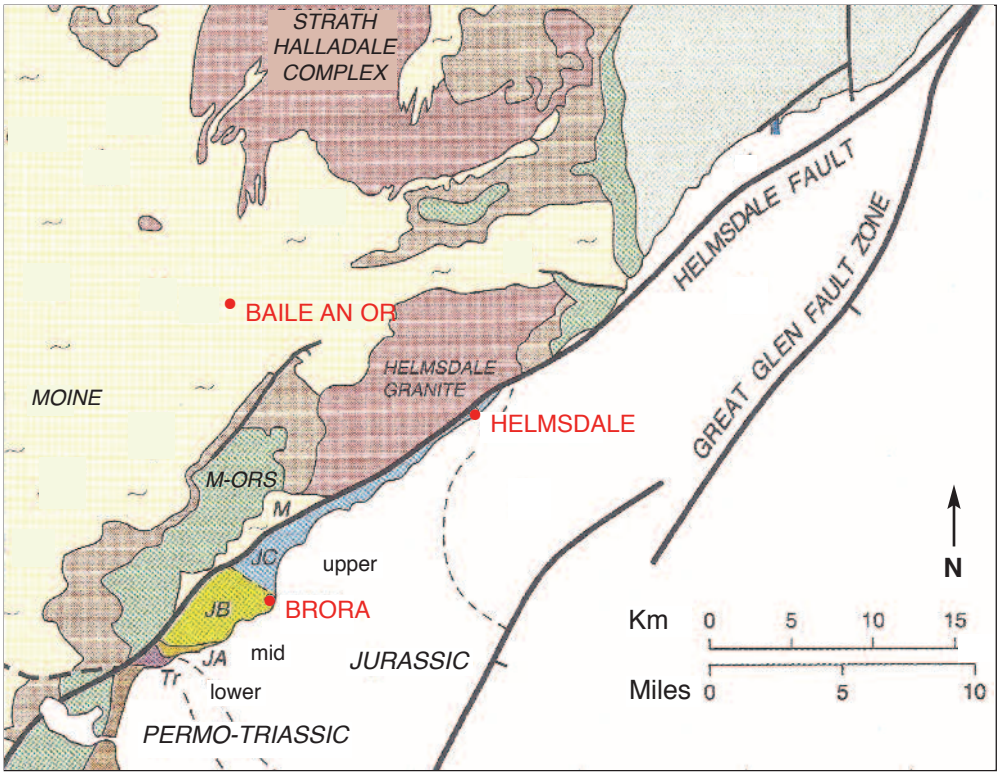


Figure 1 The geology of the Helmsdale area (after Trewin and Hurst (eds) 1983, with permision).

Our day started not in the Jurassic, but in Lower ORS strata, as we inspected a quarry at Ousdale. The exposure comprised a number of thick (*c*. 300mm) fining-up units, each erosively deposited on the previous one. The base of each sequence consisted of large feldspar and quartz clasts and led to the first puzzle of the day: how to distinguish granite from arkose? The source material for both the Ousdale arkose, which underlies the Ousdale mudstones here exposed, and the coarser units in these beds, comes almost entirely from a grus formed by deep weathering of the Helmsdale Granite (a Caledonian 'Newer Granite'). Since the crystals have travelled little before being deposited in sheets by flash floods and relithified, the texture is almost identical to that of the original granite, fooling many a seasoned geologist. While some of the more confident thought we could distinguish them in the field, a thin section is desirable for unequivocal identification.

Trace fossils can be found in the finer-grained units. Highly abundant was *Diplocraterion*, the burrows in cross-section forming spots and short lines across the rock. We also searched for arthropod trackways (traces such as *Rusophycus* and *Cruziana* can be found here) but the poor light was a hindrance to finding these elusive trace fossils.

The quarry showed other interesting phenomena. Climbing ripples, desiccation cracks, tool marks and longitudinal ridge structures (i.e. parallel to flow direction) were found on bedding planes. A cobble of granite showed the effects of iron leaching in the form of iron pan (Fig. 2). A thin red line separated a pale zone at the top from a pink zone at the bottom. This shows how even a rock as seemingly impermeable as granite still has a small degree of porosity and permeability, as water passes along the crystal boundaries, in the process aiding the weathering of the rock. On occasions iron pan can bear a striking resemblance to cross-bedding, something we could easily believe from pebbles found later on the beach.

Thick mist threatened to spoil our next locality, but luckily we descended just far enough to get a view across the Helmsdale coast and see the structure of the rocks laid out before us. On the shore are seen a number of ridges (the harder units in the Helmsdale Boulder Beds) curved into a series of seaward-plunging synclines and anticlines, with anticlines forming prominent headlands on the coast. It is hypothesised that the folding is

Figure 2 Iron pan in a granitic boulder (photo by M. Perkins).

© OUGS ISSN 0143-9472

Figure 3 Modern day (left) and fossil (right) boring bivalves (photo by M. Perkins).

caused by stress in Tertiary times between opposing movement on the Helmsdale fault and the Great Glen Fault (Thomson and Underhill 1993).

The Moray Firth is a basin of broadly synclinal form, with Jurassic, Cretaceous and Tertiary rocks outcropping on the seafloor. The visibility did not allow a view of the Beatrice oilfield, but Prof. Trewin explained that the kerogen from which it formed has a somewhat enigmatic origin, probably partly Jurassic and partly Devonian, with oil migrating up-dip to a reservoir in Middle to Upper Jurassic rocks (Trewin 1989).

Our next stop took us to examine the Helmsdale Boulder Beds up close. Leaving the cars in Helmsdale, we walked along a storm beach of large cobbles, picking up pieces of the local lithologies. These included ORS breccias, Helmsdale granite and Ousdale arkose. Many cobbles had been drilled by modern boring bivalves, making holes of up to 20mm in diameter, often completely penetrating the rock. While this is a modern phenomenon (often the shells of animal are still present in the holes), the same mode of life existed in the Jurassic. A specimen (found on a previous trip) showed very similar bivalves fossilised in their burrows in a cobble that was evidently exposed on the Jurassic sea bed, suggesting a Jurassic storm beach very like that which exists today (Fig. 3).

Figure 4 The Helmsdale Boulder Beds (photo by M. Perkins).

Figure 5 A clast of Isastraea *in the Helmsdale conglomerate (photo by M. Perkins).*

The Helmsdale Boulder Beds themselves comprise large clasts embedded in a finer-grained, shelly matrix (Fig. 4). The clasts were primarily of the Caithness flags — some having been found containing fossil fish! — with no Helmsdale granite or Ousdale arkose present. This shows that these latter lithologies did not outcrop here at the time. However, textural maturity was not uniform, as both highly angular and rounded clasts present. The beds also contained plant material, and large cobbles of fossil wood (permineralised by calcite) could be found on the beach. Also present in the beds were clasts of the colonial coral *Isastraea*, which we picked up among the loose beach material (Fig. 5).

Shell debris in the matrix indicates that these conglomerates formed under marine conditions, with many the rounded clasts coming from a storm beach. However, the textural immaturity of other clasts leads to a more violent interpretation of the beds' origin: earthquakes. A large submarine fault scarp would have existed just off the Jurassic palaeo-coast, with movement not only causing brecciation, rockfalls and debris flows from the scarp, but also tsunamis that would sweep beach deposits and terrestrial material back to the deep as they withdrew. These tsunami deposits were thick but occasional; in between finer-grained shales and sandstones were deposited, representing the majority of geological time and recording more common events such as storms. However, these softer beds have been

Figure 6 A sandstone dyke on the Kintradwell shore (photo by M. Perkins).

preferentially eroded by the sea, leaving the boulder beds sticking out in ridges on the shore.

The downthrow of the Helmsdale fault occurs to the east, making the position of the Jurassic palaeo-coastline surprisingly close to that of today. We picked out the present-day position of the fault in the distance, juxtaposing the Boulder Beds and the Helmsdale granite, although time did not permit us to examine it at close range.

A short trip down the coast to the Kintradwell shore led to the next locality, and to some strata that fell more closely in line with our Jurassic expectations. The black shales contained abundant ammonites and belemnites, but also more surprisingly contained some large, cobble-sized clasts. This seemed rather in contrast to the low-energy environment that would be needed to deposit the shales. Nonetheless, these large clasts were rare, leading us to conclude that these Kintradwell Boulder Beds were formed at greater distance from the fault scarp than those we examined earlier at Helmsdale. The lithology of the clasts was also different to that at Helmsdale, and changes rather sharply just north at Portgower. The rocks exposed in the headwall must therefore have been somewhat different here in the south, and suggest that another fault may have cut across the Helmsdale fault at Portgower.

The familiar form of a dyke ran seaward across the beach. Close examination showed it to be sandstone. Though available evidence cannot rule out filling from above, it seems likely this was intruded from below during an earthquake, as an underlying, unlithified sand, liquified and intruded through a fresh crack in the overlying sediments (Fig. 6).

Some of the beds exposed on the shore showed excellent examples of locally folded and disturbed sediments. This is not tectonic folding, but instead the result of soft-sediment deformation and slumping of coherent rafts of sediment on the sea floor. Beneath some undisturbed sands, for example, we found folded muds, while elsewhere a boulder rested on essentially undisturbed sediments, suggesting it may have slid into place down the submarine slope. In other places, chunks of folded sandstones of varied orientations stood proud from the beach (Fig. 7).

Our final stop of the day took us to view the 'Fallen Stack' of Portgower. This is a 30m × 15m block of sub-vertically-bedded ORS sediments. As its name implies, it was originally interpreted as a toppled sea stack but is now known to be a giant clast in the Helmsdale Boulder Beds. The clast probably fell from the submarine fault scarp, showing that the scarp was at least 30m high. Several such giant clasts are found in the vicinity.

Taking stock of all we had seen during the day enabled us to put together a mental picture of life here in the Jurassic. Close to the coast, the sea teemed with life, including ammonites, belemnites and colonial corals. On land, large trees grew. But the area was tectonically active and not far offshore a steep submarine fault scarp ran sub-parallel to the coast. Periodic movement on this fault not only caused parts of the submarine cliff to become detached and topple over, but also led to violent tsunamis, which washed ORS boulders, chunks of coral, and trees over the shelf edge, forming thick, highly immature boulder beds separated by the less voluminous but temporally dominant finer-grained deposits.

Day 2: May Baile an Or and Brora

Anne Morton

Baile an Or

Sunday morning's excursion was to 'Baile an Or' or the Gold Village, the site of the 1869 Helmsdale gold rush, to try our hands at gold panning. When we arrived we found that others were already encamped by the side of the Kildonan Burn, with serious digging and panning equipment stashed outside their tents; and a business-like party of gold-panners preceding us along the path up the burn.

Alluvial gold was found at Kildonan Burn about 1840, but not in any quantity until R. N. Gilchrist returned from Australia in 1868 — it was he who started the Helmsdale gold rush. Gold was found in moraine terraces bordering the streams. These terraces were intensively dug out during the gold rush, causing serious erosion of the stream banks and affecting the fisheries downstream. Industrial-scale exploitation is now forbidden, and gold panning is strictly controlled by regulations displayed on a

Figure 7 Folded sediments stick up from the shore (photo by M. Perkins).

Figure 8 Gold panners in action (photo by M. Musur).

Figure 9 Prof. Trewin explaining the Brora stratigraphy (photo by M. Musur).

noticeboard at Baile an Or. On the Suisgill Burn, gold panning is strictly prohibited except for certain specific exceptions, one of which being that you are a pensioner over 70 accompanied by a lady, make a written application giving the exact dates of your intended visit, and keep a copy of your written permission with you at all times.

The country rock here consists mainly of flaggy Moine psammites or sandstones with thin layers of pelite or clay-rich horizons showing amphibolite facies metamorphism. The ultimate source of mineralisation was probably granite and quartz veins, which cut the Moine metasediments. The granite is part of the Strath Halladale migmatite complex (both the Older and Newer granites), so the date of primary mineralisation is uncertain, but may be Devonian in age. Mineralisation probably centred on the watershed of the Suisgill Burn. Gold from the Suisgill Burn is more silver-rich than that from Kildonan. The distribution of gold has been influenced by subsequent weathering, erosion and glacial and fluvial action.

While only a few of us found gold (Fig. 8), we all ended up with dark grains of ferromagnesian minerals and small pink garnets. Several of us also found tantalising grains of pyrite or 'fool's gold'. As we were leaving for lunch, an old-timer approached us to display his pan containing (to our eyes, at least) quite large flakes of gold.

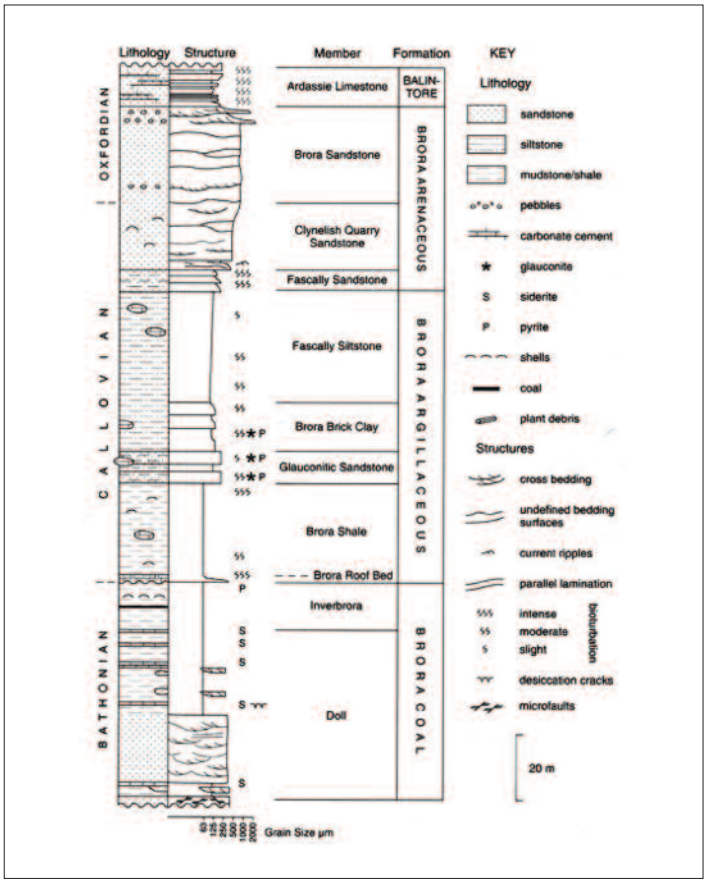
Brora

Starting at the car park overlooking the mouth of River Brora, we followed a path along the top of the beach as far as the sewage pipe, which is anchored to the Brora Roof Bed (Fig. 9). The Brora Roof Bed overlies the Brora Coal (Bathonian age) and is the basal bed of the Callovian Brora Argillaceous Formation, deposited during the Lower Callovian marine transgression. Above this in the succession is the Brora Shale (exposed only at very low tides), which represents open marine conditions and is rich in belemnites, ammonites and bivalves, grading upwards into lagoonal sediments with plants and molluscs comparable in age with the Great Estuarine Bed of Skye (Middle Jurassic) (Fig. 10).

Before we stepped down onto the beach, Prof. Trewin showed us some examples of fossils we would be looking for. This included a piece of the Brora Shale containing shells fragmented not by wave action but by predation by fish and arthropods. He also had a repaired specimen of a belemnite about 8in (203mm) long; the modern equivalent of this fossil would be the internal shell or 'bone' of a cuttlefish. Normally only the hard internal skeleton remains, but the soft parts of belemnites (e.g. impression of the eyes, ink sac and tentacles) have been recovered from the Lias at Lyme Regis, Dorset. Another beautiful example shown to us was a heart-shaped bivalve found in the Lias at Dunrobin, not far from Brora.

As we walked south along the beach, our attention was drawn to a block of Brora sandstone (quarried locally for building stone), showing *Pecten*-type shells and voids, which make this stone very permeable and porous, and therefore a useful oil reservoir where it occurs offshore in the North Sea. This block was not *in situ*, but originated probably from a quarry south of Strathsteven Cliff, higher up in the sequence.

Figure 10 The stratigraphic sequence at Brora (reproduced from Trewin and Hurst (eds) 1983, with kind permission from the publisher).



A prominent, low ridge of hard, siliceous sandstone seamed with quartz veins marked the line of the Brora Fault where it crossed the beach. This belonged to the Brora Arenaceous Formation and displayed slickensides and fault-rock. The downthrow of the fault is in the opposite direction to that of the Helmsdale Fault, the sediments having been displaced 250ft (76.2m) lower to the north-west. The fault movement may have occurred during the Cretaceous. The line of the Brora Fault is marked by the occurrence of very hard, well-cemented sandstone (Fig. 11), preserving an early stage of diagenesis by hydrothermal fluids rising up the fault plane. One possible source for this silica could have been the diagenetic solution of sponge spicules.

Crossing the beach exposed at low tide, we saw a variety of modern ripple forms, and reflected on how they would be expressed after lithification. About halfway along the beach towards our objective, the Sputie Burn tumbles over a waterfall into a pool of water before sinking into the unconsolidated boulder ridge at the top of the beach and percolating through to form a broad wash flowing down the beach towards the sea. Subsequently we reached the prominent landmark of Strathsteven Cliff (Fig. 12), a remnant of the Clynelish Quarry Sandstone (Brora Arenaceous Formation) once quarried locally for building stone.

Strathsteven Cliff shows large-scale cross-bedding typical of a large sand bar. The beds near the foot of the cliff dip seawards at 30˚, those in the middle dip more steeply, and the beds at the top of the cliff become sub-horizontal. This would suggest a large coastal sand bar oriented parallel to the coastline of the time, forming part of a bar system punctuated at intervals by tidal channels.

Figure 11 Well-cemented sandstone of the Brora Fault (photo by G. Ramos).

The remainder of the afternoon was spent returning to the rocks of the Brora Coal and Roof Bed for a closer look, keeping a sharp eye out for fossils. The Brora Coal had formed in a lagoonal setting where the plants initially grew as a floating mat in water too deep for a normal seat-earth to form, so that few rootlets are found. The environment was one of intermediate salinity, with a high-abundance, low-diversity fauna. From time to time the sea

Figure 12 The Strathsteven Cliff (photo by G. Ramos).

would break into the lagoon, winnowing the shell beds by wave action to produce a shell hash on the floor of the lagoon. The Inverbrora Member includes some bituminous shales and thin lenses of coal with pyrite concretions. Marie Stopes, more famous for promoting birth control, described fossils from these rocks derived from drifted plant material, including Equisetum and pine trees (also mentioned by Hugh Miller) *[Ed. — Readers interested in Stopes' work as a palaeobotanist are referred to* 'Marie Stopes — palaeobotanist' *by Bill Chaloner,* OUGSJ ***29*** *(2), 26–30.]*. We saw some very soft black shale with plant fragments, and also a piece of oily shale that weathered soft and coloured brown on breaking, containing pyrite indicative of reducing conditions.

The overlying Roof Bed was bioturbated by burrowing bivalves. In addition, rock surfaces were encrusted with gastropods and bivalves. Moving into the Brora Shale, we found glauconite (the Glauconitic Sandstone), characteristic of sediments laid down in marine conditions. The rocky platform at the low-tide mark was studded with fossils, and belemnites were particularly abundant (Fig. 13), together with bivalves, including oysters.

While the day's trip had come to an end, the Brora localities had certainly given plenty of insight, inspiration and scope for fossil collecting, and some of us returned with their bags rather heavier than at the beginning of the day. Alhough the same cannot be said of our successes at gold hunting, we were content to go back richer in knowledge if not in means. For those able to stay for the final day, our searching would take in some quite different lithologies.

Day 3: Achanarras Quarry
Jenny Allan

The famous fish beds at Achanarras Quarry, are of mid-Devonian age — the rocks are part of the Old Red Sandstone succession, *c*. 385 million years old. Several species of fish once inhabited Lake Orcadie, a large Devonian lake, situated within the Orcadian basin, extending from Caithness to the Orkney Islands. The well preserved fish fossils are assumed to have resulted from occasional mass mortalities, caused by fluctuations in water levels and salinity. The fish remains sank to the bottom of the lake and were covered by successive layers of mud and silt.

Figure 13 Belemnites were abundant and well preserved (photo by M. Perkins).

Fossil fish species identified from the quarry include representatives from the Dipnoans (lobe-finned), Actinopterigian (ray-finned), Placoderms (armoured fish), Agnathans (lamprey-like), Acanthodians (spiny-finned) and *Palaeospondylus*, a strange zip-like 'zoological enigma'.

During the 19th Century, these mudstones were extensively quarried for flagstones, but this activity ceased by the early 20th Century. There was a later resurgence during the building boom of the 1950s, when the quarry was briefly reopened to supply roofing slates. The flagstones split readily along horizontal planes. Achanarras Quarry has become a Mecca for fossil hunters worldwide and is now a Geological SSSI. Fossil collecting is allowed from spoil heaps, but damaging undisturbed rock faces is strictly forbidden.

For personal reasons, Prof. Trewin was unable to accompany us on Monday's excursion to Achanarras Quarry. However, excellent leader that he is, he took time to prepare us beforehand after the Brora outing. From the rear of his car, he produced the 'goodies', excellent exemplar specimens of the fish fossils we were all hoping to find, although specimens as good as these were unlikely to be encountered. Also, as he explained to us, the best specimens had involved hours of specialised work, uncovering the intricate fish structures. Some fossil fish outlines could be discerned within the flagstone slices. In these cases, Prof. Trewin advised against splitting the rocks, instead obtaining specialist help, possibly from a museum, in order to uncover a complete specimen. When a fish-containing flagstone is split, twin fossil fish imprints are often revealed to a delighted 'splitter'.

Prof. Trewin showed us several different fossil specimens of the primitive lung fish *Dipterus*, including 'split twins' (Fig. 14a, and b, *opposite*). There was also an excellent specimen of the

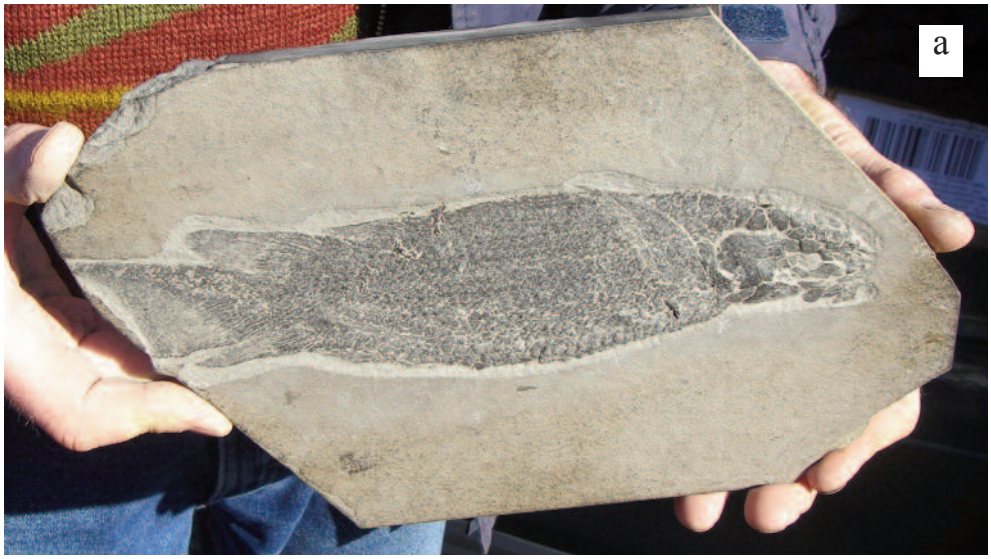


Figure 14a and 14b (opposite) Specimens of Dipterus*, the most common fish at Achanarras (photos by J. Allan).*

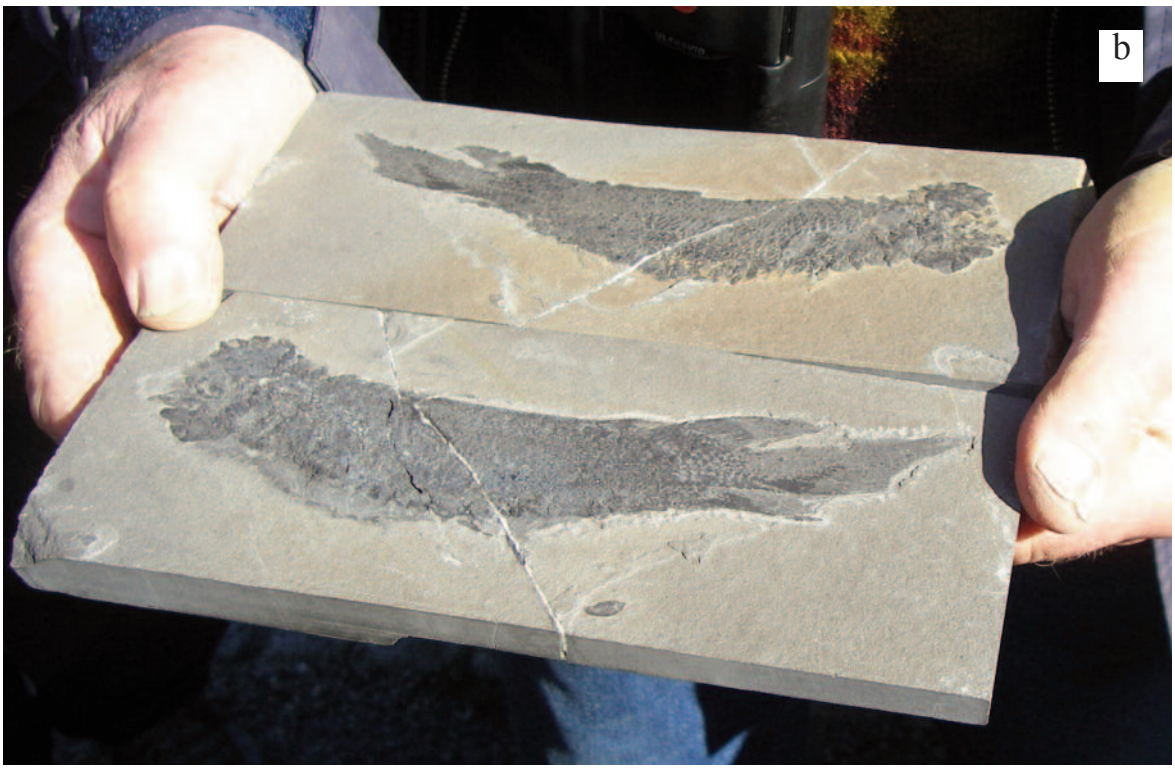


Figure 15 (below) The 'paddle fish' Pterichthyodes (photo by J. Allan).

Figure 16 (above) Achanarras Quarry and the shelter (photo by J. Allan.)
Figure 17 (below) Searching the spoil heaps at Achanarras (photo by J. Allan).

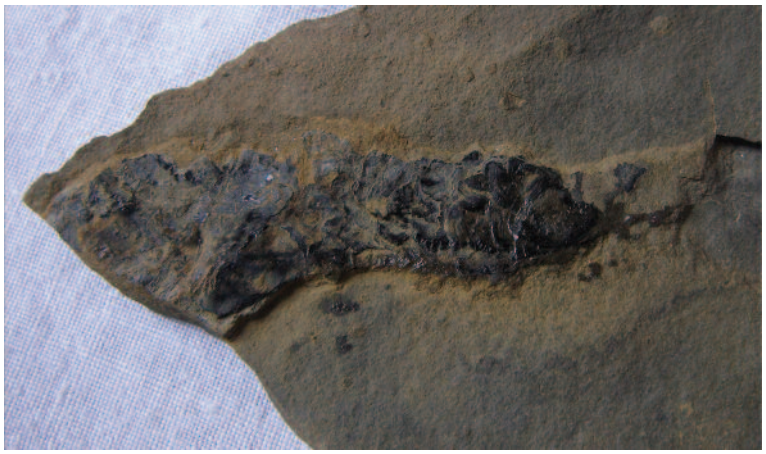
curious armoured fish, *Pterichthyodes*, first discovered by Hugh Miller at Cromarty in the 19th Century (Fig. 15, *page 81*). This fish has 'paddle-like' pectoral fins.

He told us that the tiny 'zip-like' fish, *Palaeospondylus*, was common in the quarry, but the specimen he showed us was just too tiny to be photographed.

On Monday the excellent sunny weather continued, and after saying our goodbyes to Prof. Trewin and the other departing members of the party, the remaining 11 of us made our way north to the quarry, situated near Mybster on the road to Thurso (Fig. 16, *opposite*). Before leaving Helmsdale, Michael Perkins visited the local hardware store, with several orders to buy chisels in anticipation of rock splitting. Again Prof. Trewin had given us precise instructions, including drawing us a map from the car park to the quarry, and highlighting the best areas to search.

On reaching the quarry, we spread out and searched individually for fossil finds (Fig. 17, *opposite*). Having neither hammer nor chisel, I chose an area that had been recently bulldozed, exposing a large area of fresh flagstone faces. My one and only fishy find was encountered within the first few minutes, but I never found another specimen. The rounded scales on this incomplete specimen (Fig. 18) indicate that these remains are from a *Dipterus* fish fossil. There were also numerous examples of fossil fish 'poos', or to give them their proper academic title, 'coprolites'.

After an hour or two, and our coffee and packed lunches having been consumed *ad hoc* on flagstone 'tables', time was called, since a long drive home awaited us. A short debriefing was held by Michael within the little shelter-cum-interpretive-centre recently built on the site, and our collective finds were shared, photographed and enthused over. Michael found a complete fish specimen (Fig. 19), and Ann Morton split a flagstone to reveal two excellent 'twin' fish specimens. Both fish finds are assumed to be *Dipterus* species. Other finds, included a specimen of *Palaeospondylus* (Fig. 20), found by Michael.



Acknowledgments

Our grateful thanks for an excellent weekend are due to organiser Michael Perkins and our expert leader Nigel Trewin. We were all provided with copies of his SNH leaflets 'Fossil Fish of Caithness'. He has also written books on Scottish fossils and fossil hunting, as well as the 'Bible', the *Excursion Guide to the Geology of East Sutherland and Caithness*, co-authored by Andrew Hurst.

The leaflet, *Fossil Fish of Caithness*, produced by Scottish Natural Heritage, can be downloaded free at:
http://www.snh.org.uk/pdfs/publications/earthscience/FossilFishofCaithness.pdf

References

Thomson, K., and Underhill, R. 1993 'Controls on the development and evolution of structural styles in the Inner Moray Firth Basin', *in* Parker, J. R. (ed.) *Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference*. London: Geological Society, 1167–78

Trewin, N., and Hurst, A. (eds) 1983 *Excursion Guide to the Geology of East Sutherland and Caithness*. Edinburgh: Dunedin Academic Press

Trewin, N. 1989 'The petroleum potential of the Old Red Sandstone of northern Scotland'. *Scott J Geol* **25**, 201–5

Figure 18 (above left) Jenny's patch of Dipterus *scales. (photo by J. Allan).*
Figure 19 (below left) Mike's complete fish (photo by M. Perkins).
Figure 20 (below) Palaeospondylus *(photo by M. Perkins).*

Book review

Martin, Seelye 2014 *An Introduction to Ocean Remote Sensing* (2nd edn). Cambridge U P (ISBN 978-1-10701-938-6; 454pp; hardback £50)

This is a textbook for graduate-level students taking advanced courses in Oceanography, Remote Sensing or Environmental Studies and supplies practical information for researchers and professionals working in these fields. This second edition reflects the increase, over the last decade, of the number of satellites and computer resources used to explore the many aspects of oceanic properties and received recognition from the scientific community for its exceptional work.

The book looks at the variety of satellites orbiting the globe, how their orbits vary and affect the coverage of data collected. It describes the physical science of the surface layer of the ocean, its biota, waves and ice, the atmosphere and the properties of electromagnetic radiation (EMR) and how it can be used in this field. It then describes the interactions of all of these factors and how different wavelengths can be used to record data about the ocean. Woven into the descriptions are the necessary mathematics and physics required to understand the phenomena being described and to use the data sets produced by the systems.

This complex book has been written by a practitioner who is aware of the requirements of the user, but he presents the required information in a concise and yet accessible form. It is not any easy book to read, but if one is a worker in this field all the relevant information appears to be there. It is well laid out with chapters on each type of satellite imager, and the use of laser and radar in measuring the geoid and ice topography and thickness.

There is access to a wide range of information both within the book and through the publisher's website. The book contains tables of past, present and future satellites, pictures and diagrams of the instruments used, schematics to describe the science, b&w and colour images of data from the satellites and much more. All of which are available digitally through the website, along with a portal to archive data and tools to work with the data. It is fully indexed and referenced.

When I received this book I was a little daunted by the complexity of the subject, but I have been able to use my Earth Science degree knowledge to gain a better idea of this important area of study and how it is necessary to our understanding of climate change.

— Averil Leaver BSc Hons Geoscience (Open)

Book review

Cattermole, Peter 2014 *Introducing the Planets and Their Moons*. Edinburgh: Dunedin Academic Press (ISBN paperback 978-1-78046-029-1, e-publication 978-1-78046-513-5, Kindle edition 978-1-78046-514-2; 142pp; paperback £9.99, Kindle edition £8.59)

This little book is full of detailed information, anticipating the current Rosetta exploration of the comet 67P (12/11/2014) together with continuing and future exploratory programmes.

There are 12 basic chapters, a full list of tables and illustrations, a useful glossary and a list of books for further reading. Many of the illustrations are from NASA and JPL, including Hubble Space Telescope photographs and artist illustrations. A helpful addition would be diagrams of the relative positions of each set of planet with its moons.

There are detailed descriptions of the surface features and analyses of the compositions of each planet and moon, as far as is possible to date. In some cases the analysis has been from actual samples, such as those from the Earth's Moon and from Mars.

Rather than take each planet separately, each chapter makes comparisons of the planets.

Chapter 1 is a general descriptive introduction; Ch. 2 describes the probable origin of the Solar System; Ch. 3 introduces the Planets and their orbits; Ch. 4 discusses planetary differentiation; Ch. 5 describes the magnetic fields; Ch. 6 planetary atmospheres; Ch. 7 geological development of the inner planets; and Ch. 8 volcanism within the inner Solar System.

The Earth's moon is discussed in Ch. 9; Ch. 10 covers the outer planets; Ch. 11 the moons of Jupiter and Saturn; and Ch. 12 the moons of Uranus and Neptune.

I would recommend this book to anyone looking for detailed and up-to-date information (as at March 2014) to complement other studies.

It is written well by a man who worked with NASA. As he says, it is not an exhaustive treatment, but rather intended to inspire readers to investigate more of the subject.

— Rosemary Darby BA (Open), BSc Hons (Open), Certs Ed. (UK, NZ)

OUGS Severnside field trip to Nash Point, South Wales
(led by Tom Sharpe)

John de Caux

Figure 1 Nash point from the car park.

A group of Severnsiders visited Nash Point on the coast of South Glamorgan (Figs 1, and 2, *overleaf*) to look at the Porthkerry Formation of the early Jurassic Limestone succession. Our leader, Tom Sharpe, explained to us that these are often known as the Lias, a name that probably originates from an old quarrying name for layers.

We met at the very windy car park and descended to the foot of Nash Point. The many Limestone layers of the formation have been categorized into different units: A, B, C and D (Fig. 3, *overleaf*).

Only the upper three units are visible at Nash Point (Fig. 4, *overleaf*). The lowest of these (Unit B) contains distinctive marker beds known as the Sandwich Beds, which consist of two continuous beds separated by four or five rubble beds. The Sandwich Beds are traceable along the base of the cliffs well beyond the area we traversed (Fig. 5, *overleaf*)

Walking east along the beach we traversed Limestone beds that dip at *c*. 5˚ W so that we crossed gradually younger rocks during the day. The gentle slope of these beds and the large tidal range of the Severn estuary means that some of the largest areas of single bedding planes visible anywhere are exposed at low tide (Fig. 6, *page 87*)

The vast number of fossils in these beds is proof of how fertile the sea must have been in the past (Figs 7–10, *pages 87–8*).

After lunch on the beach below Atlantic College we moved farther east to Stradling Well, where there are two faults separated by a graben that has brought unit D down to the level of the Sandwich Beds east and west of the graben (Fig. 11, *page 88*).

The cliffs at this point are being covered by tufa (Fig. 12, *page 88*).

Since the tide had turned by this time and was fast covering the beach it was decided not to proceed any farther east and we returned to the car park along the South Wales Coastal Path, which runs along the cliff top.

On the return we passed the two Nash Point lighthouses (only one of which is operational), erected following a spate of shipwrecks on the sand bar just off the coast.

Acknowledgement
We are indebted to Tom Sharpe for a very interesting day among some of the youngest rocks in South Wales.

© OUGS ISSN 0143-9472

Figure 2 Severnside Branch members at Nash Point.

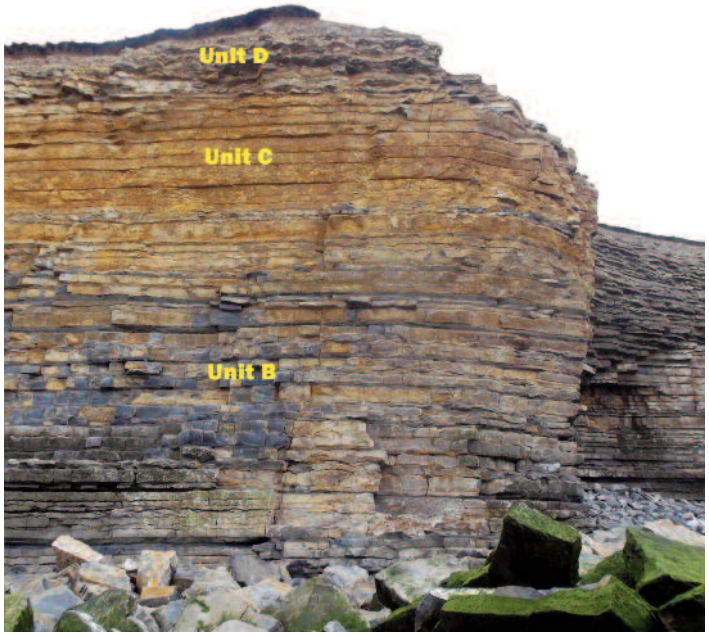


Figure 4 Units B, C and D of the Porthkerry Formation at Nash Point and the marker horizons.

Figure 3 Early Jurassic stratigraphic succession at Nash Point.

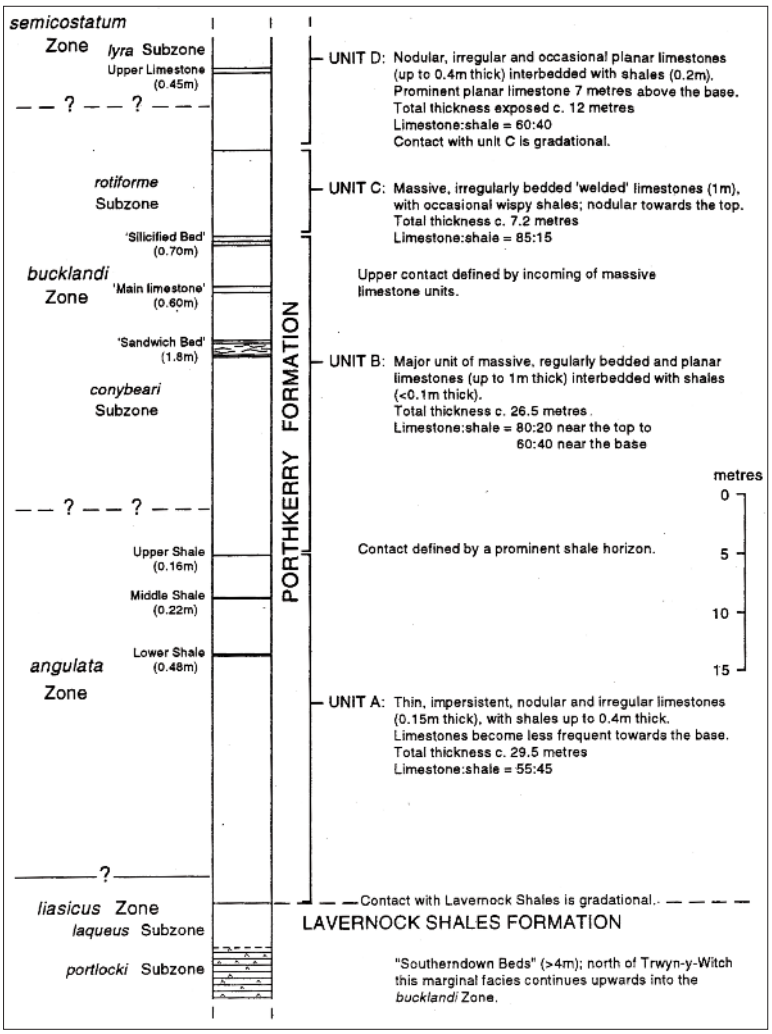

semicostatum Zone
lyra Subzone
Upper Limestone (0.45m)
rotiforme Subzone
'Silicified Bed' (0.70m)
bucklandi Zone
'Main limestone' (0.60m)
'Sandwich Bed' (1.8m)
conybeari Subzone
Upper Shale (0.16m)
Middle Shale (0.22m)
Lower Shale (0.48m)
angulata Zone
liasicus Zone
laqueus Subzone
portlocki Subzone
PORTHKERRY FORMATION
UNIT D: Nodular, irregular and occasional planar limestones (up to 0.4m thick) interbedded with shales (0.2m). Prominent planar limestone 7 metres above the base. Total thickness exposed c. 12 metres Limestone:shale = 60:40 Contact with unit C is gradational.
UNIT C: Massive, irregularly bedded 'welded' limestones (1m), with occasional wispy shales; nodular towards the top. Total thickness c. 7.2 metres Limestone:shale = 85:15
Upper contact defined by incoming of massive limestone units.
UNIT B: Major unit of massive, regularly bedded and planar limestones (up to 1m thick) interbedded with shales (<0.1m thick). Total thickness c. 26.5 metres. Limestone:shale = 80:20 near the top to 60:40 near the base
metres
0
5
10
15
Contact defined by a prominent shale horizon.
UNIT A: Thin, impersistent, nodular and irregular limestones (0.15m thick), with shales up to 0.4m thick. Limestones become less frequent towards the base. Total thickness c. 29.5 metres Limestone:shale = 55:45
Contact with Lavernock Shales is gradational.
LAVERNOCK SHALES FORMATION
"Southerndown Beds" (>4m); north of Trwyn-y-Witch this marginal facies continues upwards into the bucklandi Zone.

Figure 5 Cliffs east of Nash Point.

Figure 6 Gently sloping bedding planes east of Nash Point.

Figure 7 Nash Point: pinna (cross section in life-position) and bi-valves.

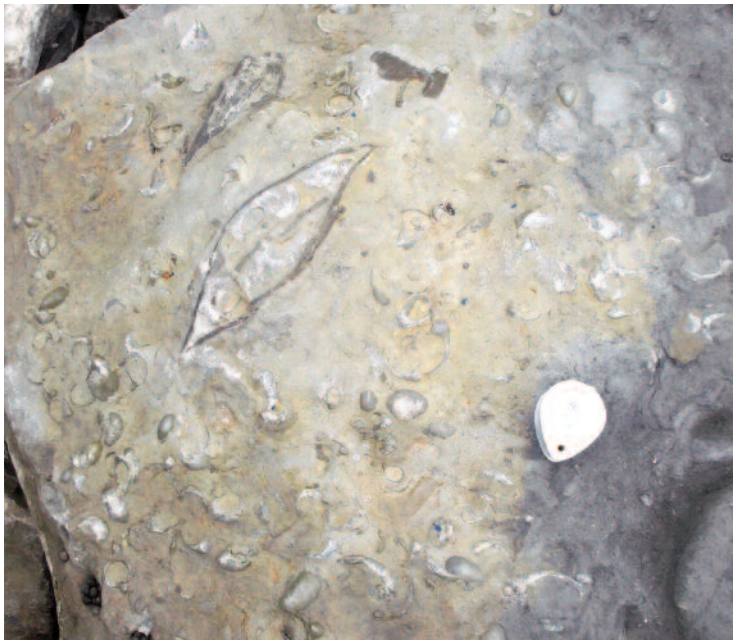


Figure 8 Nash Point: ammonite.

Figure 9 Nash Point: gastropod.

Figure 10 Nash Point: star-shaped fragments of stems of the Crinoid Pentacrinites.

Figure 11 Graben at Stradling Well.

Figure 12 Tufa on cliff at Stradling Well.

Blue crystals from Canada

Lyn Relph

Travelling along the southern coast of the St Lawrence Seaway [on the most recent Severnside Branch 'Sutures on a Shoestring' field trip], we stopped for lunch at Saint-Maxime-du-Mont-Louis, a very small harbour. The seaward promontory had been reinforced with rock armour; these huge boulders sparkled in the sun, so off to investigate. There were the usual minerals: calcite, peacock ore, but also some pretty pale blue crystals (Fig. 1). The origin of the boulders was thought to be the Murdochville copper mine some way inland.

I collected a sample of the blue crystals for later identification. Some months later, still puzzled, I showed them to Jonathan Wilkins; his first thought was that they are molybdenite, but he was not entirely certain, so he took the sample to run an XRD analysis.

This is the e-mail I received a few days later:

> Under the microscope I dissected some of the brightly metallic crystals. It appeared to be, as I suspected, molybdenite. The bluish sheen, soft, sectile, metallic, bladed habit — everything. I managed to collect about 100mg, and tried to crush it. Yuck! It smeared everywhere, giving more credence to molybdenite. By wetting the agate with acetone and rubbing carefully around I managed to collect most of the dispersed material and concentrate it by agitating and evaporating the acetone naturally. Then onto our special XRD mount for small samples. I was expecting a pair of peaks near 20 degrees, but shock horror it came up at 16.5 deg first, with much lower peaks going all the way to 60 deg (Fig. 2, *overleaf*).
>
> Time to consult the oracle. Tungstenite, WS2 — just like molybdenite MoS2 — and sharing almost every characteristic. Yours is the H2 polymorph, one of two documented. There are some small unmarked peaks which are quartz and calcite, which I did not manage to avoid. VERY UNUSUAL.

Life had suddenly got very exciting, not just for me but also for Jonathan and some of his colleagues! Tungstenite is so very rare that for reasons described below this result needed confirmation.

Molybdenite and Tungstenite have the same S2 composition; only the crystal lattice is very slightly different. The XRD analysis measures the angle of diffracted light passing through this lattice. Jonathan explained that:

> At higher diffraction angles the small discrepancies are exaggerated, the main difference apart from relative intensities of the peaks (not entirely objective in my experiment due to the difficulties mentioned) is that the peak at 60 degrees splits in tungstenite, but remains single in molybdenite. You may see that in the plot (Fig. 2, overleaf) if you look at the guide-lines. It is difficult to do the comparison from a tabular listing, so I am hoping my colleague will be able to give me an illustration. My system refuses point-blank to admit that it is molybdenite.

So which is it? The frustrations of modern technology! This is the next communication I received from Jonathan:

> Revised PDF document attached (Fig. 3, *overleaf*).
>
> XRF determined unequivocally that it was Mo and not W. Note that Mo, W, Cr are in the same column of the periodic table — hence certain structural similarities and affinities. Playing with my software finally elicited a pattern recognition for molybdenite by X-ray powder diffraction. The small peak, which is not labeled at 26.65 deg is quartz contamination — very useful, as it enables a definite XRD goniometer calibration on the sample.

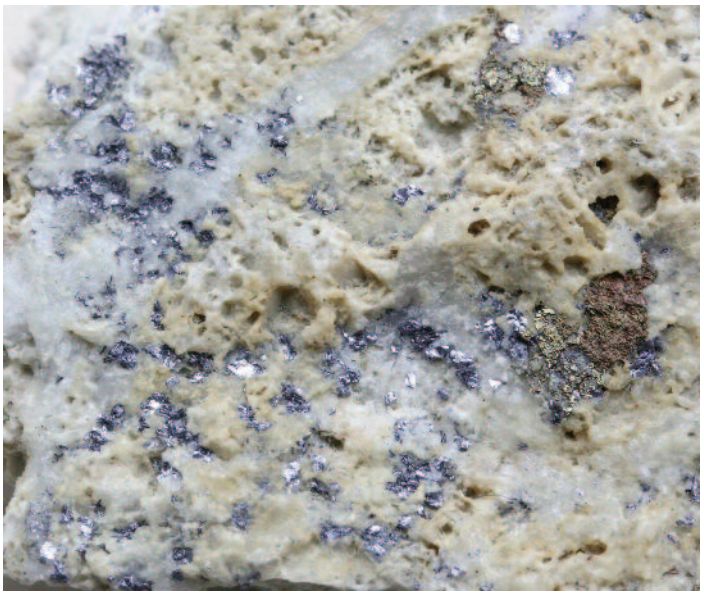
This is the definitive answer confirmed by two methods.

The final bit of information was from the Murdochville mine website, which states that Molybdenite was mined at the site, and was therefore probably the source of the boulders by the harbour at Saint-Maxime-du-Mont-Louis.

For me this has been an interesting insight into geological analytical technology and the workings of a crystallographer; also to get my pretty blue crystals identified.

I am indebted to Jonathan Wilkins (who many of you will know from field trips to North Wales and Anglesey) for this analysis, also to X-ray Mineral Services Ltd and X-ray Analytical at St Andrews University.

Figure 1 Pale blue crystals from the rock at Saint-Maxime-du-Mont-Louis promontory, Canada (photo by Lyn Relph).



© OUGS ISSN 0143-9472

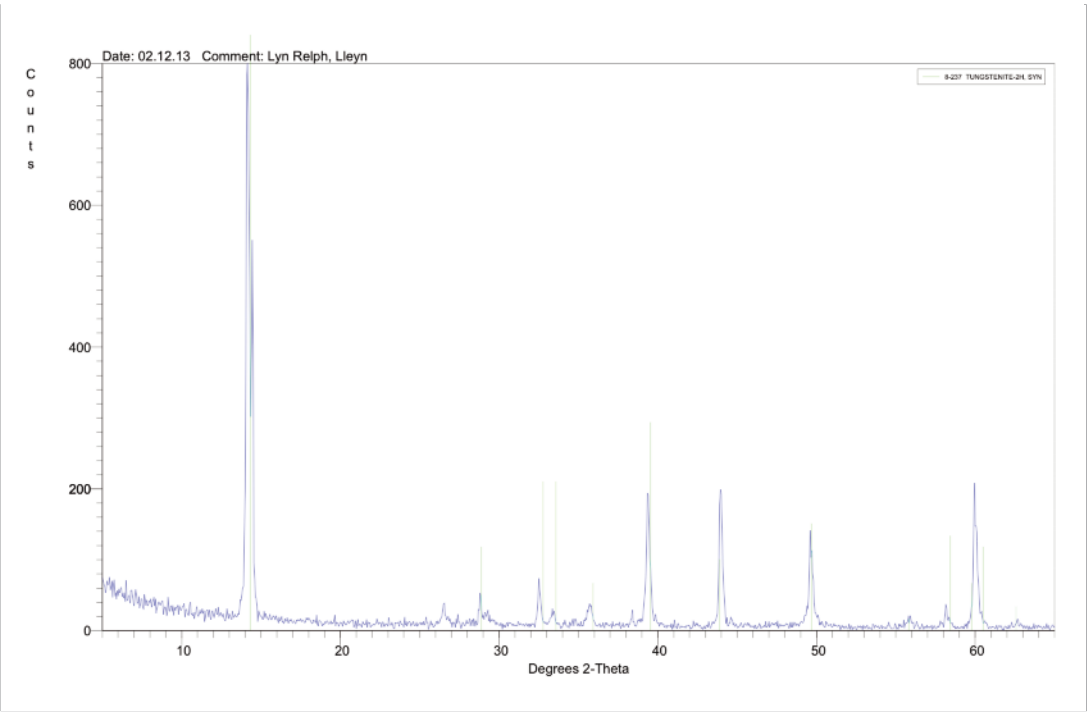
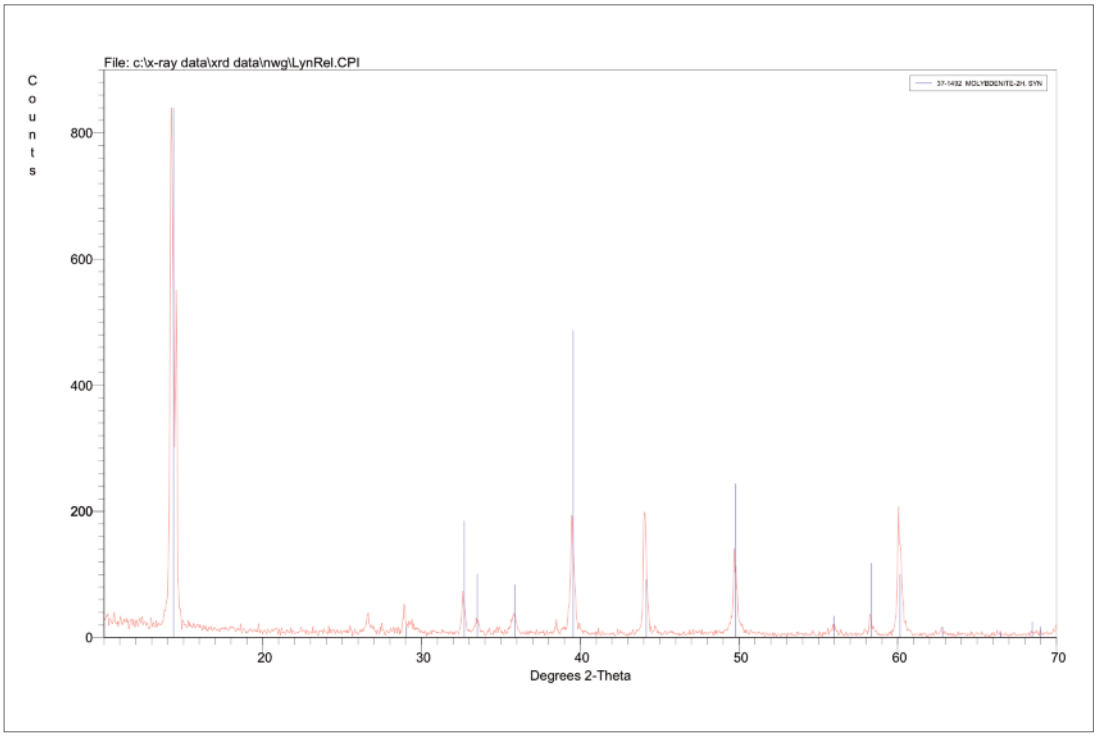


Figure 2 XRD analysis of blue crystals in rock from Saint-Maxime-du-Mont-Louis promontory, Canada.

Figure 3 XRF analysis of blue crystals in rock from Saint-Maxime-du-Mont-Louis promontory, Canada.



Wessex OUGS weekend field trip to Shropshire

(1–3 November 2013; led by Joe Jennings (OU) and Ben Matthews (Tarmac))

Lawrie Bubb, Christine Hodgson, Alan Holiday and Helen Phythian

Bayston Hill Quarry (2 Nov 2013)

Alan Holiday

Bayston Hill Quarry is located south-west of Shrewsbury just off the A49 (SJ490089). The quarry is operated by Tarmac and Lafarge. Company policy means that there is no public access to the quarry proper, or the associated rock faces. However, there are some good viewing points around the quarry partly accessible from public rights of way.

The rock being worked is of late Precambrian age, Longmyndian (Bayston-Oakswood Formation deposited *c.* 560 million years ago). It occurs as an inlier surrounded by Upper Carboniferous Coal Measures, which are not of economic interest. The quarry is *c.* 1km long and 300m–400m wide.

The Precambrian 'gritstone' has a near vertical dip and is a mixture of conglomerate and greywacke sandstone. The sandstone consists of mineral and lithic clasts in a clay matrix. The greywacke did not form in the usual way — as a deep-water turbidite deposit, but was deposited in times of sheet flooding on alluvial plains.

Quarrying began at what was Sharpstone Hill, but the hill has now been largely quarried away! The quarry is exploiting the sandstone material located between two bands of conglomerate — Darnford and Haughmond — which are of less economic interest. The coarser sediments were probably formed as braided river channels. The sandstone doesn't show much of the typical features of greywacke sandstones such as graded units. However, rip-up clasts are also present, consisting of fragments of muddy sediment included in a later sandstone unit associated with the erosion of former flood plain areas, that is, a low-energy environment (Fig. 1) (Toghill 2006).

The sediment was deposited in a down-faulted trough that was formed during a period of tension and is now in an overturned synclinal structure between the Church Stretton and Pontesford Faults. The quarry is on the eastern limb of this syncline.

The region is mentioned in J. N. Carney and J. M. Horak in their Geological Conservation Report (GCR) 'Precambrian Rocks of England and Wales' (2000), but unfortunately the Bayston Hill Quarry is not described, although the relatively nearby site of Lyd Hole is (SJ 414055).

The quarry has been in existence since the early 1900s and has become a major producer in the last 40 years. At the beginning of the last decade an extension of the quarry to the north was allowed, which facilitated working to greater depth, following the dip of the strata. Further expansion is planned beyond 2015, possibly continuing to 2050 and making the quarry *c*. 100m wider and working it to *c*. 100m deeper.

The rock quarried is ideal for making rock chips for the production of asphalt. It is made of clasts, which are held together by a relatively weak cementing matrix (the clay). This means that when incorporated into the road surface the stone wears away continually but slowly, without forming a smooth surface and creating the danger of skidding. Lower-grade material — the conglomerate — can be used for road base.

In quarrying, structural stability is important, so that the quarried benches and roadways are safe (Fig. 2, *overleaf*). Sliding is not so much a problem, but jointing can be, especially when working across the strike to accommodate faulting, which displaces the best rock. The rock is released by blasting, which frees-up between 20,000 and 60,000 tons at a time. Currently *c.* 1 million tons of rock is produced each year and this is limited by planning controls and the transport of products by lorry from the site affecting the local towns and villages. However, the reinstatement of a railway link is planned, which will enable increased production, for rail transport becomes viable if production is greater than 1 million tons per year. The quarried stone is transported in 75-ton dump trucks to the primary crusher within the quarry before being transported by conveyor elsewhere on site for further crushing, screening and washing, which enables separation into different grades for various uses, but mainly selecting 10mm–14mm material for asphalt. In the production of asphalt, the rock chips are mixed with sand from a nearby sand and gravel pit comprising Pleistocene glacial material.

The product from Bayston Hill is reckoned to be among the best asphalt in the world and the quarry has a ready market for its products, being close to the A5 with good access to the West Midland conurbation. Some of its asphalt was even transported to the Middle East for surfacing the Bahrain and Abu Dhabi grand prix circuits — if you are rich, money is no object when you want the best! The recent economic downturn has affected production, but there have been signs in recent months of significant improvement in demand.

During the development of the site there have been some interesting finds, including a pre-Roman road, which suggests that Iron Age people were road builders. In the Coal Measures material, which rests unconformably on the Precambrian rock, some good fossil tree specimens have been found and some of these

Figure 1 Example of a rip-up clast in sandstone at Bayston Hill Quarry (photo by A. Holiday).

© OUGS ISSN 0143-9472

Figure 2 Quarry benches at Bayston Hill Quarry (photo by A. Holiday).

can still be seen on site (Fig. 3). The fossils include tree trunks and patterned stem material of Lepidodendron trees (an extinct species related to club mosses).

Environmental issues are important to the quarry operators, including the creation of a large barrier around part of the site to avoid visual intrusion on the landscape and to reduce noise. Trees have also been planted to screen the site. Water released from the site is checked for particulate content so that it does not pollute local water courses. Blasting is carefully controlled to avoid vibration issues affecting local dwellings, especially in cloudy conditions.

Figure 3 Lepidodendron tree trunk at Bayston Hill Quarry (photo by A. Holiday).

An interesting corollary to our visit is that one of the rocks included in the Geological Terrace at Bournemouth University is from the Bayston Hill Quarry, but identification has not yet been achieved.

The Ercall (2 Nov 2013)

Christine Hodgson

Geological history of the area

In the late Precambrian southern Britain was close to the Antarctic Circle, on the margin of West Gondwana, which then formed part of the Vendian supercontinent. As the result of oceanic crust subduction, the Cadomian Volcanic Arc led to a variety of igneous, metamorphic and sedimentary rocks forming terranes on adjoining areas. About 580Ma Baltica and Laurentia rifted away from Gondwana. The Avalonian Orogeny, a complex episode of folding and faulting, took place between 570Ma and 550Ma as the sea floor of the newly formed Iapetus Ocean spread. Oceanic crust was subducted under the edge of a northward-moving Gondwana, causing compression to occur at an oblique angle. This 'transpression' initiated horizontal tear-fault movements that both sliced and repositioned terranes, and caused crustal extension. The Uriconian Volcanics (U–Pb zircon dated 566 ± 2Ma) erupted through this thinned continental crust. The Welsh

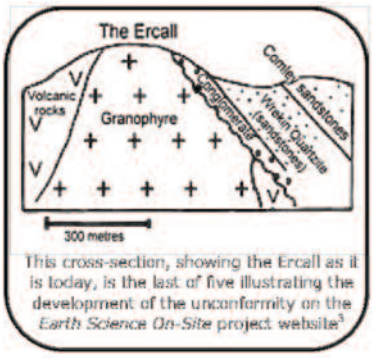

The Ercall
Volcanic rocks
Granophyre
Conglomerate
Cambrian sandstones
Wrekin Quartzite (sandstone)
300 metres
This cross-section, showing the Ercall as it is today, is the last of five illustrating the development of the unconformity on the Earth Science On-Site project website[3]

Figure 4 Cross-section, showing the Ercall as it is today (ref. http://www.ukrigs.org.uk/esos/wiki/index.php5?title=ERC/KS4/Ex).

Borderland fault system defined the margins of this tensional pull-apart basin. Earlier in the day, at Bayston Hill Quarry, we had seen part of the Longmyndian Supergroup of sedimentary rocks. These were deposited in another part of this basin when subsidence allowed marine flooding (Fig. 4).

As Joe Jennings pointed out, it is very fortunate for geology students that quarrying the Ercall opened such an important window into the igneous history of Shropshire. The earliest evidence of Precambrian rocks in the county is seen only in very small outcrops in the nearby Wrekin, one outcrop each of schist and gneiss formed from basement sediment metamorphosed between 700 and 600 million years ago. There is then a gap until the great eruptions of volcanic lavas and ashes *c*. 570–560 million years ago. Driving through the area we had passed the remains that form many of the hog-backed hills east of the Church Stretton Fault. In the Ercall quarries these sub-aerial Uriconian Volcanics, intruded by dolerite dykes and a diapir-like granophyre intrusion, are well exposed (Fig. 5). The name is taken from the nearby former Roman city of Uriconium (Wroxeter).

Figure 5 Exposure of Uriconian Volcanics at the Ercall (photo by C. Hodgson).

Following the Avalonian Orogeny the marine transgression that spread from the north-west laid down Cambrian rocks over most of the English Midlands. Uplift and erosion in many places by the mid-Ordovician, continuing faulting and folding, and a timespan of more than 500 million years has caused their major disappearance in Shropshire. One of the very limited outcrops showing this is in the Ercall — here is a dividing point in time, the run-up to the Cambrian 'explosion' of life into complex forms from simple soft-bodied animals to creatures with hard shells and exoskeletons.

The Ercall quarries

There was early use of the quarries; then quartzite extraction started seriously in the 1850s and finished in 1986 after the construction of the nearby M54 motorway. The chemical and physical nature of the rocks has made them resistant to decomposition and suitable for use in road building. For example, the quarries provided the foundations for Telford (5km east) and its roads. The area is now a SSSI owned by Shropshire Wildlife Trust and nature is rapidly taking over. The northern quarried areas have easy public access and visible exposures.

From Ercall Lane we approached the western end of a 20m high pale pink/brown rock face. The fresh-fallen hand specimens collected were mainly fine tuff — a lithified volcanic ash. Some coarser samples contained 10mm sized volcanic bombs of lava that had hardened in flight. Of much interest was fine-grained rock showing regular narrow bands 1–2mm wide, alternately pale and dark. This is known as flow banding, where minerals have streaked out as the highly viscous, silica-rich lava flowed very slowly and cooled rapidly.

The Uriconian Volcanics in this quarry are rhyolitic and thought to be some 1,200m thick. Using U–Pb zircon systematics Tucker and Pharaoh (1991) dated these at 566 ± 2Ma. Their geochemistry is consistent with that found in a modern-day island arc setting. The highly viscous lava and the explosive emissions of lavas and tuffs were likely to have been erupted from a volcano similar to Mount Pelée (ignimbrites also are present on the adjacent Wrekin). The fine ash found at the Ercall would have risen into the upper atmosphere as dust clouds, only falling to earth months later and likely miles away from its emission. The conical shaped hills of volcanic rock in this part of Shropshire are the remnants of an extensive ash and lava field. The natural landscape we see today only started to emerge in the Tertiary Period, *c.* 30 million years ago, when erosion removed great thicknesses of later sediments and exposed older rock, including Precambrian.

A huge Wrekin supervolcano, like that at Yellowstone, USA, has been proposed. To date no vents have been identified anywhere in the Midlands — they could have been eroded or are still buried.

Figure 6 Exposure of a dolerite dyke at the Ercall (photo by C. Hodgson).

As we moved eastward along the quarry face, we looked for the intrusion marked on our map — a dyke injected into the already hardened lavas and tuffs. This dark-coloured igneous intrusion is dolerite, a rock with lower silica content, indicating a late stage of volcanic activity (Fig. 6). Scree falls and vegetation did not deter the intrepid ascent by one of the party to identify a darker band in the host rock, but not to measure its width!

Continuing east along the floor of the quarries we saw the famous Ercall exposure. Then turning around, we examined a 3m high rockface showing slickensides with near horizontal striation (Fig. 7). Sheila Alderman attempted to determine direction of movement by feeling the mineral fibres that would have grown during displacement, but there had been too much erosion. This feature is a dextral strike-slip fault caused when the base of this quarry had moved north-west during one, or possibly more, of the many tectonic events affecting the area.

Although Shropshire is now well away from an active plate boundary (as it lies on the stable western margin of the Eurasian plate), minor earth movements still occur in the county. These earthquakes, *c.* 5 on the Richter scale, do not cause surface ruptures. The widening of the Atlantic Ocean generates forces sufficient to produce movements on old fault lines at depth.

Figure 7 Exposure of slickensides at the Ercall (photo by C. Hodgson).

On the far side, where the quarrying had ceased, we found the famous rock assemblage — Cambrian Wrekin Quartzite resting unconformably on the late Precambrian Ercall granophyre (Fig. 8, *opposite*). Perhaps we should refer to this as a 'nonconformity', because the Wrekin Quartzite dips owing to late Ordovician folding.

To our left we saw the pink mass of late Precambrian Ercall granophyre. This was a diapir-like intrusion of more chemically evolved magma (with higher silica content) emplaced, later in the volcanic episode, into the Uriconian lavas and ashes. Tucker and Pharaoh (1991) dated the granophyre using U–Pb zircon systematics as 560 ± 1Ma, whereas a date of 533 ± 1Ma was obtained by Patchett *et al.* (1980) using Rb–Sr systematics. This later date is interpreted to have been influenced by the deposition of the Wrekin Quartzite, which led to a redistribution of the Rb and Sr isotopes within the granophyre and a re-setting of the radiogenic clock, all of which culminated in an age of doubtful significance. However, the age can, and probably does, represent the start of sedimentary deposition in the area, and to an approximation, the maximum length of time the granophyre was sub-aerially exposed to weathering — the covering Uriconian volcanics firstly having been largely eroded. The granophyre here may be the only sizable exposure of granitic rock in the county, and it is only seen to the north of the major tear fault that bisects the quarries' area.

To our right was the steeply dipping south-east, well jointed, Wrekin Quartzite some 34m thick, with a basal conglomerate. This was about 5m metres thick and is beach gravel of the Cambrian coastline. We examined this carefully, and found that it consisted mainly of rounded Uriconian rhyolite pebbles and only rare clasts of granophyre. The latter rock readily breaks up and forms the sand particle matrix. Shale layers in the basal conglomerate contain acritarchs — primitive planktonic algae. These indicate a time above the base of the Cambrian and so the time of the marine transgression.

We discussed the term 'quartzite', which suggests a metamorphic origin. The rock above the conglomerate is best described as a quartz arenite — a pure, sugary, white unmetamorphosed quartz sandstone. Any colour was due to diagenetic coatings.

Following a bench around to the north-western quarry we saw exposures of the quartzite beds laid down as the sea encroached farther. These beds showed wonderful ripple marks and from their pattern we deduced there had been a wide beach environment with a long wave fetch and a shoreline to the south-east (Fig. 9).

We also noticed a greenish-brown sandstone, its colour familiar to those who know the Greensand of south-east England. Rock containing the mineral glauconite is totally restricted to marine environments and here confirmed the marine transgression.

This Lower Comley Sandstone is the next in the Cambrian sequence in Shropshire and the last one seen here, created by faulting (Fig. 10, *overleaf*). The Lower Comley Limestone, which rests directly on this Sandstone in Comley Quarry, Shropshire, contains the first Lower Cambrian fossils described in Britain, including the trilobite Olenellus.

Figure 9 Ripple marks in quartzite at the Ercall (photo by C. Hodgson).

Lea Quarry, Wenlock Edge (3 Nov 2013)

Helen Phythian

Wenlock Edge was formed in the Silurian period, which began *c*. 443Ma and lasted for *c*. 34 million years. The period began at the end of the Ordovician and ended with a mass extinction, after which new faunas and lithologies marked the beginning of what is now known as the Devonian Period.

During the Silurian atmospheric oxygen levels were about 15% and ambient CO_2 was 12 times higher than the present day concentration. Thus the global mean surface temperature was about 3˚C warmer than it is today. Maximum sea levels at this time are estimated to have been 140m higher than they are today; however, they rose during the early Silurian and fell again towards the end of this period, forming the limestone-reef (Fig. 11, *overleaf*).

During the Silurian the earliest bony fish appeared along with arthropods such as sea scorpions. Brachiopods proliferated along

Figure 8 The famous Ercall unconformity (photo by C. Hodgson).

Figure 10 Lower Comley Sandstone, leaving the Ercall (photo by C. Hodgson).

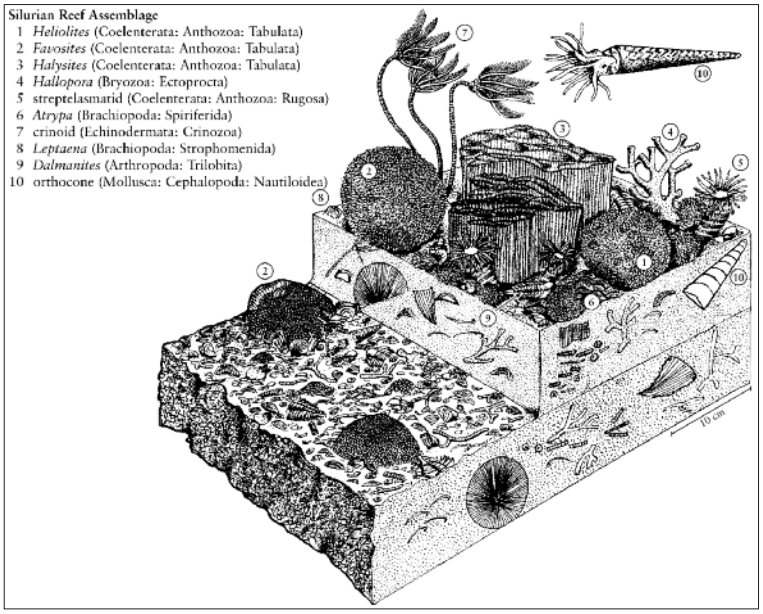

Silurian Reef Assemblage
1 Heliolites (Coelenterata: Anthozoa: Tabulata)
2 Favosites (Coelenterata: Anthozoa: Tabulata)
3 Halysites (Coelenterata: Anthozoa: Tabulata)
4 Hallopora (Bryozoa: Ectoprocta)
5 streptelasmatid (Coelenterata: Anthozoa: Rugosa)
6 Atrypa (Brachiopoda: Spiriferida)
7 crinoid (Echinodermata: Crinozoa)
8 Leptaena (Brachiopoda: Strophomenida)
9 Dalmanites (Arthropoda: Trilobita)
10 orthocone (Mollusca: Cephalopoda: Nautiloidea)

Figure 11 Reconstruction of a coral-dominated Silurian reef assemblage (from W. S. McKerrow 1978 The Ecology of Fossils: An Illustrated Guide, Duckworth, with kimd permission).

with bryozoans (sea mats), crinoids and trilobites. The most abundant fossils found were various corals, both colonial and solitary varieties. Other strange fossils too were examined and thought perhaps to be stromatolite-types. The limestone-reef fossils here are well preserved and as the site is a SSSI were found in abundance within the reef limestone of the quarry face, plus some on the floor at the base (Figs 12 and 13).

Figure 12 Fossiliferous Wenlock Limestone block (photo by A. Holiday).

The Teme Bank Trail, Ludlow (3 Nov 2013)

Lawrie Bubb

Our objective in the afternoon was to study several cliff face exposures along 400m of the 'Breadwalk riverside trail' (Fig. 14). We wanted to observe the exposures, deduce the processes involved in creating them and propose the resulting environment. Behind us were the Ludlow Bone Beds (♦ on Fig. 14, *opposite*), which were defined by Murchison as marking the end of the Silurian Epoch *c.* 417Ma; however, these beds are not now readily visible. They comprise fish bones, plant remains and fragments of charcoal, indicative of a location high in nutrients and close to land, so we hypothesised that it was a shallow marine environment, possibly deltaic or fluvial.

Location 1

This is a disused quarry face in the eponymously named Whitcliffe Beds. The rock is composed of medium to coarse,

Figure 13 Fossiliferous Wenlock Limestone block, detail (photo by A. Holiday).

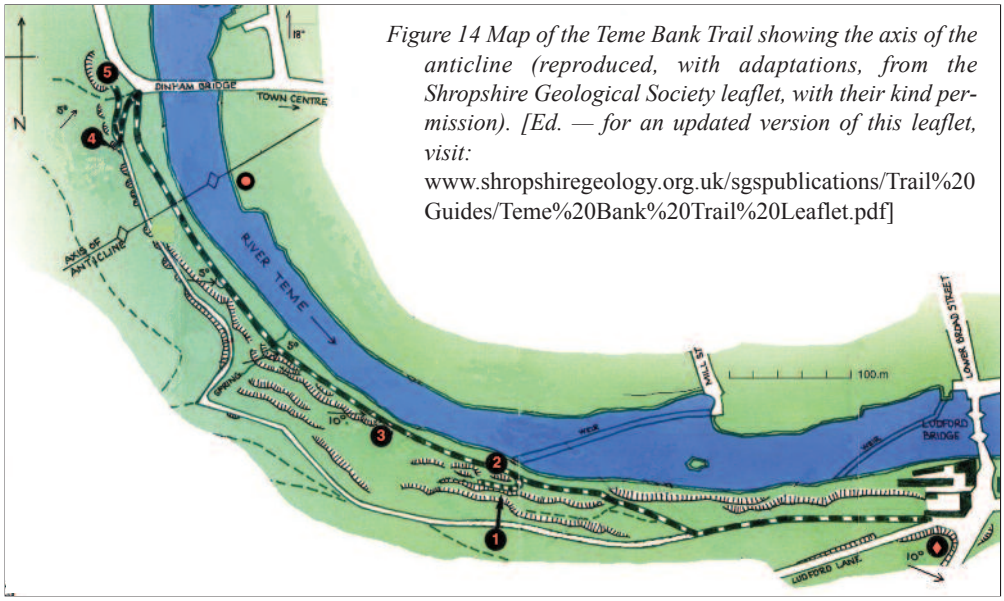


Figure 14 Map of the Teme Bank Trail showing the axis of the anticline (reproduced, with adaptations, from the Shropshire Geological Society leaflet, with their kind permission). [Ed. — for an updated version of this leaflet, visit: www.shropshiregeology.org.uk/sgspublications/Trail%20Guides/Teme%20Bank%20Trail%20Leaflet.pdf]

well-sorted, calcareous siltstone fining up in beds laid down in an irregular cyclic sequence (Fig. 15). The beds have an apparent dip of *c*. 7˚ to 8˚ SE. We observed two sedimentary structural features: in one bed, there were ball-and-pillow structures, indicating a high rate of sediment flow onto poorly consolidated previous deposits; a second bed displayed an area of cross-stratification on a 10mm scale, indicating a migrating bed with a steady current. There is little evidence of fossil remains *in situ*, although small fallen blocks at the foot of the cliff clearly showed casts of brachiopod valves. Text on the nearby information says, "Fossil shells, corals, trilobites and sea scorpions have been found in the Whitcliffe rocks".

So what processes have been in action here? The corals tell us it was warm water within the photic zone, at an equatorial latitude. The corals would have developed in a reef environment well clear of any sediment deposition. The siltstone indicates that erosion was taking place on land, and the irregular cyclicity of the beds indicate seasonal deposition in a deltaic or fluvial environment. The ball-and-pillow structure and small-scale cross-bedding reinforce an interpretation that it was an environment with irregular deposition in which the water depth was sometimes shallow.

Figure 15 Teme Bank Trail Location 1: Whitcliffe Beds (Photo by L. Bubb).

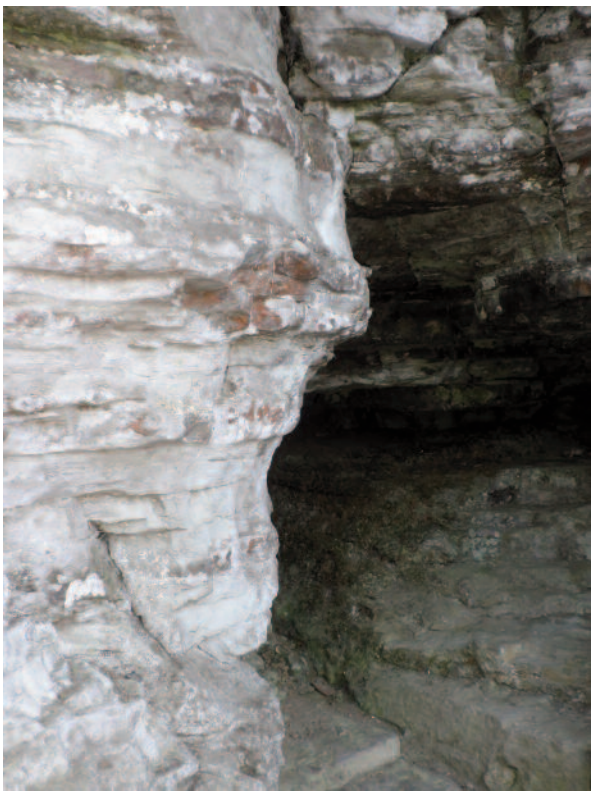
Location 2

This is near the end of the weir — another disused quarry face within the Whitcliffe Beds. This rock was used to build much of the medieval splendour of Ludlow. The beds remain with an apparent dip of a few degrees south-east. The exposure is more massively bedded, with thicknesses up to 700mm; there are also thinner beds of finer material, which may indicate a cessation in deposition. A little farther along the cliff face there are wave ripples, or possibly trough cross-stratification, in a lamina of fine-grained material. The environment here was one possibly more distal in the delta, the fine beds caused by a change in direction of the river supplying the material.

Location 3

This exposure is quite different — known as the Leintwardine Beds. The surface is irregular: there are holes in the face, and small caves. Some beds protrude and are of a more consolidated material (Fig. 16); other beds have been eroded and react when tested with 9% HCl, and crumble when touched. They are lime-rich silt, in which the lime has leached out of the rock and formed a white crust on the surface. There is some cross-stratification at 10mm scale, and generally the exposure becomes more consolidated up the face. The more prominent beds have an apparent dip of *c.* 5˚ SE and support the growth of dark red lichen (Fig. 16).

Figure 16 Teme Bank Trail Location 3: Leintwardine Beds (Photo by L. Bubb).



This exposure represents a different set of processes. There is less siliceous material from terrestrial sources and the limestone is from marine carbonate production. There is a current or tidal influence to give the cross-stratification. We can say, therefore, that these beds were deposited in an offshore environment, far from the influence of river deposits, with a prolific and healthy marine fauna.

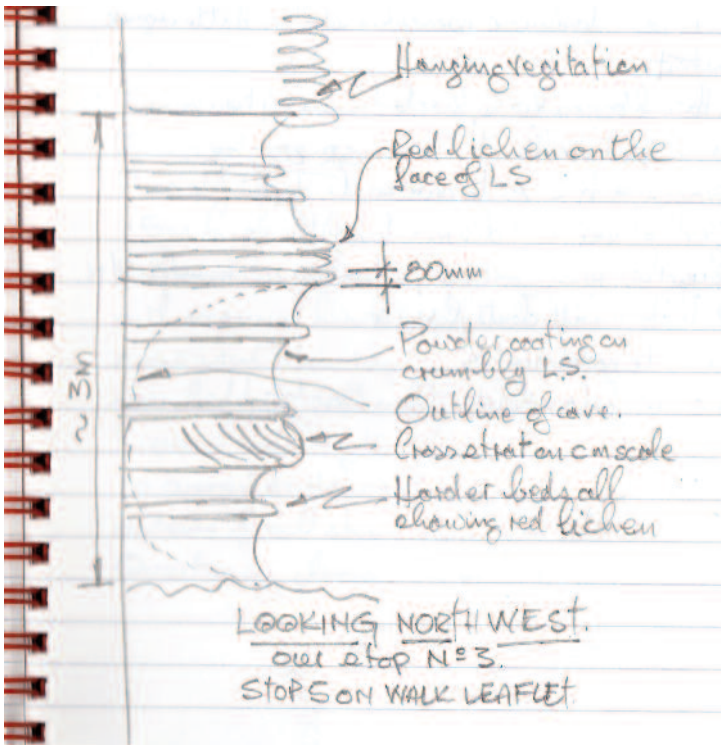
Location 4

At our penultimate location we found a somewhat similar exposure to our previous stop, once again within the Leintwardine Beds. Here the beds have an apparent dip of *c.* 5˚ NW. The exposure has what can be described as 'burrow like' cavities running parallel to the face of the cliff; this is where lime nodules or organic materials have been dissolved out of the rock by rain or river water. Some of these holes also run at various angles to the cliff face, generally within a thin bed, giving an emmental-cheese-like appearance. The processes involved and environment of deposition were similar to those described for Location 3 (Fig. 17).

Location 5

This final location was quite overgrown, but we were able to see clearly that the beds are thicker at this quarried rock face. This exposure is again of Whitcliffe Beds, comprising the medium to coarse calcareous siltstone, with an apparent north-westerly dip. There is some cross-stratification at 10mm scale. This location has the characteristics of our initial exposure.

Figure 17 Sketch graphic log at Location 3 (L. Bubb).


Hanging vegitation
Red lichen on the face of LS
± 80mm
Powdery coating on crumbly LS.
Outline of cave.
Cross stratification cm scale
Harder beds all showing red lichen
LOOKING NORTH WEST.
over stop No 3.
STOPS ON WALK LEAFLET

The anticline (● on Fig. 14)

During our 400m walk we observed the apparent dip at five locations. Initially at *c.* 8˚ SE, becoming less inclined at 5˚ SE, and then changing to 5˚ NW. The rocks change from the Ludlow Bone Beds at 417Ma, through the Whitcliffe Beds at 419Ma, to the Leintwardine Beds at 423Ma, and then returned to Whitcliffe. We had traversed the core of an anticline, the axis of which lies between Locations 3 and 4. As the beds become older towards the core of the anticline the environment of deposition changed from proximal to distal. The dip measurements taken are 'apparent', therefore, we are unable to be precise about the direction of the axis; however, in general, the axis runs south-west to north-east.

The process observed is evidence for crustal shortening. During the late Silurian the Caledonian Orogeny caused the land to rise in the Ludlow area, and generated distal to proximal depositional change. Later, in the early Devonian, the Caledonian effects became more intense in the area and major crustal shortening transpired. This shortening folded the beds to form the Ludlow Anticline, the eastern limb of which has been cut through during the last Ice Age by the River Teme.

The Breadwalk along the Teme gives a most convenient and interesting insight into this late Silurian environment.

Acknowledgements

Thanks to Ben Matthews from Tarmac and to Joe Jennings of the OU for organising and leading this interesting field trip.

There is a detailed fold-out map of the Ludlow Anticline in Earp and Hains 1971, following page 68. It shows not only the extent and beds involved, but also the nearby faults that appear to run on the north and south flanks of the anticline. This gives the area a horst-like structure, having been squeezed up by the major crustal shortening.

Cited references

Earp, J. R., and Hains, B. A. 1971 *British Regional Geology, The Welsh Borderland* (3rd edn). London: HMSO

Jennings, Joe 2013 'Field Notes' [for Lea Quarry, Wenlock Edge].

Patchett, P. J., Gale, N. H., Goodwin, R., and Humm, M. J. 1980 'Rb-Sr whole rock isochron ages of Late Pre-Cambrian to Cambrian igneous rocks from southern Britain'. *J Geol Soc London* **137**, 649–56

Toghill, Peter 2006 *Geology of Shropshire* (2nd edn). Ramsbury: Crowood Press

Tucker, R. D., and Pharoah, T. C. 1991 'U-Pb zircon ages for Late Pre-Cambrian to Cambrian igneous rocks from southern Britain'. *J Geol Soc London* **148**, 435–43

Other sources

www.ukrigs.org.uk/educ/docs/ERC

www.ukrigs.org.uk/esos/wiki/index.php5?title=ERC/KS4/Ex

Teme Bank Trail, Take a walk through Ludlow's Silurian geology can be accessed at:

http://www.shropshiregeology.org.uk/sgspublications/Trail%20Guides/Teme%20Bank%20Trail%20Leaflet.pdf

Friends of Whitcliffe Common: http://www.friendsofwhitcliffecommon.org.uk/more-about-the-geology/

Anthropocene volcano-analogue deposits near Carnforth, Lancashire: an introduction and field guide

Duncan Woodcock

(OUGS NW; d.woodcock@lancaster.ac.uk)

Abstract

Extensive dumps by the River Keer immediately west of Carnforth comprise the slag produced from the now-defunct Carnforth ironworks over a period of c. *80 years. The deposits show a number of 'volcanic' features, including glassy, chilled margins, vesicles, radial cooling cracks and 'pahoehoe dribbles', together with graded beds of granular slag. As well as being a part of the local industrial heritage, these deposits are a valuable teaching resource for earth science students at all levels.*

Introduction.

The Carnforth ironworks was established in 1846, using haematite ore available locally. The opening of the Furness railway in 1857 gave access to extensive haematite deposits in Furness and enabled rapid expansion of the ironworks. By 1870, four blast furnaces were in production, with two Bessemer converters installed a year later to convert the impure pig iron product to steel. However, by 1890 Furness ore was becoming scarce and had to be supplemented with iron ore from Spain until the ironworks closed in 1929 (Peter 1985). Figure 1 shows the location of Carnforth ironworks and the slag dumps.

Haematite ore comprises iron oxide (Fe_2O_3). Within a blast furnace it is reduced to metallic iron by reaction with carbon:

$$2Fe_2O_3 + 6C = 4Fe + 3CO_2$$

If both the haematite and the carbon were pure, there would be no slag. In practice, the haematite ore and the coal used as the source of carbon contain silicate impurities that must be removed from the blast furnace or they will accumulate.

Figure 2 Dark, glassy margin, around 10mm thick, on the outer surface of a broken piece of slag. The lighter grey interior comprises fine-grained crystalline material.

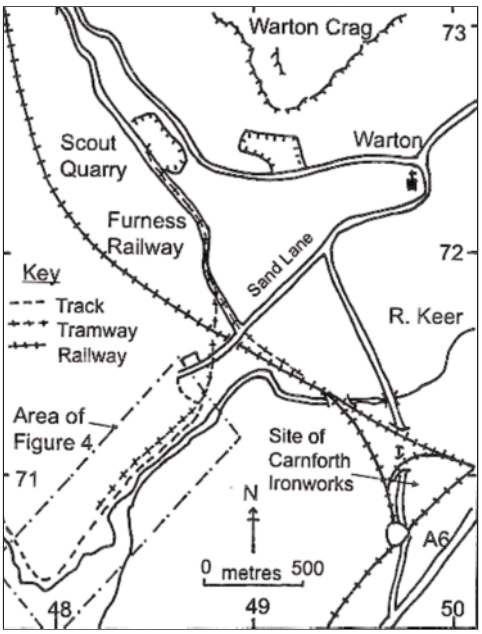


Figure 1 Sketch map of Carnforth and Warton. A railway line (marked 'tramway') linked Carnforth Ironworks with the slag dumping area on the north-west bank of the Keer estuary and with Scout Quarry — the source of the limestone for the blast furnace.

Limestone is added to the blast furnace feed to react with the silicate impurities to produce slag: a mixture of calcium silicate minerals that has a lower melting point than iron. Furthermore, the slag forms an immiscible layer that floats on the liquid metallic iron at the base of the blast furnace. The liquid slag is tapped periodically and channelled down into slag ladles for disposal.

Slag ladles were transported by rail to the dumps when a sufficient number of full ladles had accumulated to make up a trainload. Consequently, each slag ladle on a trainload cooled for a different length of time before dumping. Where the contents of slag ladles cooled sufficiently to break up thoroughly on dumping, the deposits often show bedding, each bed comprising clasts of slag from a single ladle.

On occasions the contents of a slag ladle remained intact on dumping: the resulting cylinders of slag, with a diameter of about a metre, indicate the size of the slag ladles in use. The contents of a slag ladle of this size take about a day to solidify to the centre (Butler 1977). Thus a ladle dumped less than a day after tapping may have dribbled molten slag if it broke on dumping: this can be seen in a few places in the Keer deposits.

The slag 'dribbles' are the most obvious feature that demonstrates the once-molten nature of the deposit. Other features that attest to a molten origin include:

- A dark glassy margin on many of the broken pieces of slag (Fig. 2), and on the exterior of unbroken cylinders of slag, where molten slag has quenched against the cold metal of the ladle.

© OUGS ISSN 0143-9472

- Spherical bubbles (vesicles) in the fine-grained crystalline material; these were produced as gas exsolved from the molten slag during crystallisation within a static environment in the interior of a slag ladle.
- Cooling contraction joints, including radial joints within complete cylinders, caused by the volume reduction on cooling and solidification.
- Blobs of iron, now rusty, on the base of complete cylinders. This iron originated from the top of the molten iron layer in the blast furnace and became entrained in the last dregs of slag to be tapped. The iron then sank through the molten slag to the base of the ladle.

Figure 3 Coarser-grained crystalline material from the centre of a slag mould.

Field Guide

Figure 4 shows the area of part of the slag dumps. From Warton village proceed up Sand Lane and continue south-west over the railway bridge to Cotestones Farm [SD 487 714]. Park in the layby opposite the farm, taking care not to block the farm entrance. Continue south-west along the road to the gate and then south-east to the Keer estuary at Location 1.

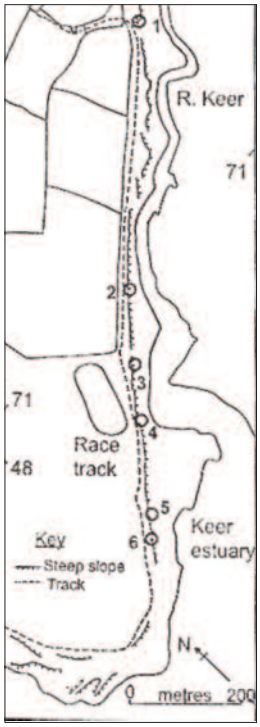


Figure 4 Sketch map of part of the slag dumping area, showing the locations referred to in the field guide.

Location 1 [SD 4875 7371]

The slag deposits at this location are the nearest ones to the location of Carnforth Ironworks and are thus probably among the earliest. Close examination of the deposit reveals several features that demonstrate its origin. There are good examples of dark glass and of spherical vesicles (Fig. 5, *opposite*) in the lighter grey finely crystalline material. Cooling contraction cracks are common and in places the deposit is 'cube-jointed', similar to cube-jointed basalts produced by the interaction of basalt lava with ice.

The Keer deposits thus show a number of features that may also be observed within natural extrusive volcanic deposits such as lava flows.

Much of the slag deposit is glassy or fine-grained; however, coarser-grained material (Fig. 3) can be seen at various locations, particularly in the cores of broken slag cylinders. Thin sections of a suite of coarser-grained material are being prepared and examined. A short note on the petrography of these samples, which have unusual mineralogies and textures compared to natural igneous rocks, is planned.

Blast furnace technology

Up to the end of the 16th century, iron was usually produced locally in bloomeries. This involved heating iron ore with charcoal to produce a 'bloom': a porous mass of iron and slag. The bloom required repeated hammering and reheating to produce a useable product: wrought iron.

Development of modern blast furnace technology began in the early 17th century, when charcoal was replaced with coke. This produced sufficiently high temperatures to melt the iron produced, and thus allow separation of iron by gravity from the molten slag co-product. When Carnforth ironworks was built in 1846 blast furnace technology had developed into a chemically and thermally efficient process.

Iron ore, coke and limestone are charged into the top of the furnace. This charge is progressively heated, and the iron ore reduced to iron, by counter-current contact with the blast furnace's gases rising upwards. Molten iron and slag accumulate in the base of the furnace where they are periodically tapped. Residual heat (and fuel) in the blast furnace gases leaving the furnace is recovered to preheat the air feed (the 'hot air blast') and to produce steam to drive machinery on the ironworks.

The deposit shows faint traces of bedding, produced as the material was dumped. At the top of the deposit, towards the north-east end, there is a black, octagonal body (Fig. 6, *opposite*): this is probably a 'slag mould' of the interior of one of the slag ladles used at the time to transport slag to the dumps. More recent cylindrical slag moulds can be seen later on the excursion at Locations 4 and 6. Continue along the north-west bank of the estuary past additional low slag deposits to Location 2.

Location 2 [SD 4839 7099]

Around this locality the slag deposits are particularly well bedded. The lower beds dip 20–30° SW along the estuary and are overlain by a prominent horizontal feature. Examination of the beds above this feature show that slag was later dumped directly towards the estuary. The horizontal feature is thus an unconformity.

Location 3 [SD 4827 7085]

This location is marked by a prominent 'cave' in bedded, relatively fine-grained and well-sorted material that is probably unique in the slag deposits. Figure 7 (*opposite*) shows a close-up view of the bedding, which resembles beds of lapilli in natural pyroclastic fall deposits; however, close examination of the clasts in the deposit reveals small pieces of brick. The origin of this particular batch of material within the ironworks is unknown — perhaps it was produced during a particularly vigorous spring clean.

Figure 5 (above) Location 1: Spherical vesicles in light-grey, fine-grained crystalline material.

Figure 6 (below) Location 1: Octagonal slag mould, c. *1m across, with dark glassy exterior. The deposit immediately to the right shows cube jointing.*

Figure 7 (right) Location 3: Beds of well-sorted clasts that resemble pyroclastic fall deposits, apart from the red fragments of brick (handle of hammer 30mm wide).

Figure 8 Location 4: Horizontal slag mould embedded in slag deposit (cylinder cross section c. *1m in diameter).*

Figure 9 Location 4: Slag 'dribble' that resembles a pahoehoe flow (field of view 350mm × 500mm).

Location 4 [SD 4823 7082]

This location is immediately opposite a prominent bend in the river channel. Two cylinders, with a diameter of *c.* 1m, are displayed in the low cliff of the slag deposit. The cylinders have dark, glassy margins, a well-defined pattern of vesiculation and a poorly developed radial joint pattern (Fig. 8).

Adjacent to one of the cylinders, at ground level under a slight overhang, there is a spectacular slag dribble (Fig. 9) with a ropy surface similar to natural pahoehoe flows.

Location 5 [SD 4811 7067]

Three almost complete cylindrical slag moulds are prominently displayed here (Fig. 10) in addition to the fragments of several broken moulds. The cylinders have glassy exteriors, vesicles in the more crystalline material and rusty iron patches (Fig. 11, *opposite*) indicating the original base of the slag ladle contents as they cooled and the denser iron separated by gravity.

Location 6 [SD 4808 7063]

At this location, additional slag cylinders are displayed. In front of one, which looks like it may roll down, is a further 'slag dribble' (Fig. 12, *opposite*). The slag deposits extend south-west towards a prominent point (with a bench), which has good views over Morecambe Bay. Additional slag was dumped in a line along the coast north-west of the point. These picturesque deposits are best enjoyed from the shore, which may be traversed with care if tides are favourable.

Figure 10 Location 5: Three almost complete cylindrical slag moulds.

References

Butler, B. C. M. 1977 'Al-rich pyroxene and melilite in a blast-furnace slag and a comparison with the Allende meteorite'. *Mineralogical Magazine* **41**, 493–99

Peter, D. 1985 *Warton with Lindeth: a history. Part 1: Communications and Industry*. Preston: Lancashire Library

Figure 11 Location 5: Patch of iron (rusty) at the base of a slag mould.

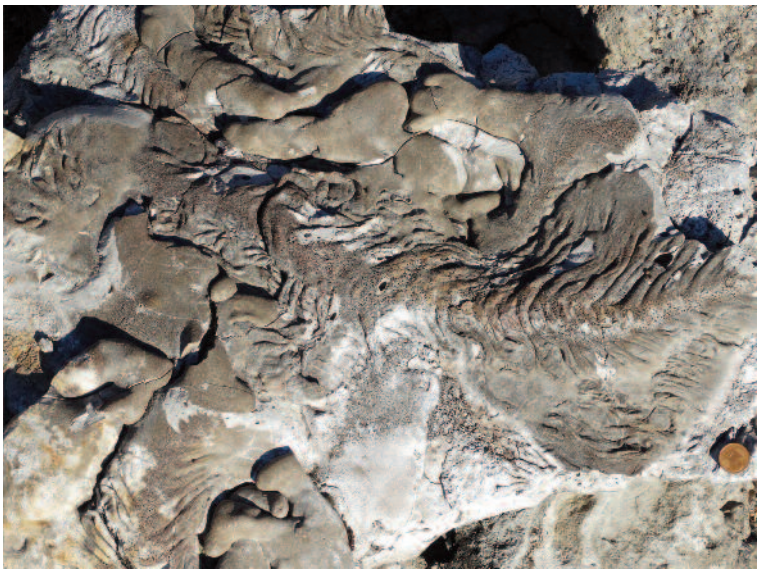


Figure 12 Location 5: Slag 'dribble' resembling a pahoehoe flow (coin diameter 26mm).

Editor's notes to contributors

Following are guidelines for the submission of articles to the *Proceedings of the OUGS*. The principal theme encompassed within these guidelines is 'please keep it simple'. Let your editor do his job and please do not try to simulate, emulate or reproduce the page layout of the *Proceedings*. I have dedicated page-layout software (QuarkXPress) to do this and any special formatting, special characters and embedded illustrations that you include in a word-processing document can be lost (at best) or seriously confuse and crash (at worst) my iMac or the QuarkXPress software when I import it into the layout.

If your article contains special characters (such as mathematical symbols), please draw these to my attention — I will probably spot them anyway — so that I can import them properly with the glyphs menu in QuarkXPress.

Here are the basic guidelines. I will contact you about any queries that arise when I read your article. I will send you an edited version, showing you any changes that I have made and raising any queries or requesting any missing information.

Guidelines for *OUGS Proceedings* articles

As *OUGS Proceedings* Editor I do not want the publication of your article to be more work than is necessary for you (or for me!). Your article need not be more than about 1,500 to 4,000 words in general, but I leave the length up to you to suit the material you are writing about.

Regarding articles from the presenters of lectures at the OUGS Symposium, all OUGS members are grateful to you for presenting a talk at the OUGS Annual Symposium, and for agreeing to submit a version of your talk for publication in the *Proceedings*. The purpose of this is to make your information available to OUGS members and others who could not attend the symposium. As OU students and OUGS members we enjoy hearing and learning the information these symposia bring to us.

All that is necessary are:

• A Word (or compatible) file of the text: There is no need for you to attempt to format the text in any way using tools in Word or other word-processing software. I will do the page layout format in the *Proceedings* house style, using dedicated publication-industry-standard page-layout software (QuarkXPress). However, feel free, if you wish, to use **bold** and/or *italics* to indicate headings and subheadings so that I can set these into house style.

I do not require a hard copy, but if you need to point out special characters or attributes in your paper, it may be a good idea to send one with these items marked up or otherwise highlighted. Otherwise I can accept electronic files attached to an e-mail, or files on a CD.

• Each illustration, chart, graph, map or other illustration as a separate digital file in high resolution: 300dpi minimum for colour or half-tone images; 1200dpi for line illustrations. Tables composed in Word or Excel are fine, as they are just text. A rough guide to the number of figures in an article is 10 to 30. Obviously as a symposium presentation speaker you might have shown numerous slides, so please use your best judgement on the number to include with the paper to be published — again usually 10 to 30 is only a rough guide.

• Please be sure that we have permission to publish any illustrations that are not yours: Also, please give me the appropriate information to cite in acknowledgement in the figure caption; and please tell me in writing or in an e-mail message that you have obtained the permission necessary for each illustration in your article that is not yours.
As the author, this responsibility is yours.

• Please do *not* embed your illustrations in Word picture boxes within the text: All that is necessary is to indicate, by a reference within ( ) or within [ ] in your text, where the illustration should go.

• You can submit the material as attachments to e-mails to me or send it to me on a CD: I am on BT Broadband, so I can receive large files. It is usually best to attach only a few illustration files each to several e-mails. This applies especially to large files of photographs, charts and graphs. Alternatively, a digital sharing package can be used, such as Dropbox or similar.

• Where appropriate, cite your sources, or make it clear that a statement is a supposition, or solely your own view or opinion. We use Harvard style citations in the text: (author date, pages), e.g. (Jones 2004, 51–3); and your sources or references should be listed in alphabetical order by author and date at the end of your article. You need to list the author, date of publication (or of access to a website), full title, periodical volume and number, or place of publication and publisher, and page numbers.

If you miss out anything, I will ask you for it.

If your list includes items not cited in your text, it will be called 'Sources'; if all items in your list have been cited in your text, it will be called 'References'.

That really is it! The editing and page layout are my job, so let me do it for you. I will communicate with you as necessary as I do this, with queries or difficulties with any formats, special symbols, characters, etc, as is the task of any editor.

For you really keen authors, regarding grammar and spelling I use:

Butcher, J. 1992 *Copy-Editing: The Cambridge Handbook for Editors, Authors and Publishers* (3rd edn). Cambridge: Cambridge UP

The Oxford English Dictionary

The Penguin Spelling Dictionary 1990. London: Penguin Books Ltd

Ritter, R. M. (ed and comp.) 2000 *The Oxford Dictionary for Writers and Editors* (2nd edn). Oxford: Oxford UP

Ritter, R. M. (ed and comp.) 2002 *The Oxford Manual of Style*. Oxford: Oxford UP

Please contact me at any time about your paper:

Dr David M. Jones, *OUGS Proceedings* Editor, 41 Blackburn Way, Godalming, Surrey GU7 1JY; 01483 424308;
proceedings@ougs.org OR **ce.ocelotl@btinternet.com**

The Open University Geological Society (OUGS) or its Proceedings Editor, accept no responsibility for breach of copyright. Copyright for the work remains with the author but copyright for the published article will be that of the OUGS.